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REPORT NUMBER TR 64-1

A MANAGEMENT SYSTEM FOR HIGH-VALUE ARMY AVIATION COMPONENTS

FINAL REPORT

by B. Rosenman and D. Hoekstra
Advanced Logistics Research Office

October 1964

UNITED STATES ARMY
FRANKFORD ARSENAL
PHILADELPHIA, PENNSYLVANIA

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A MANAGEMENT SYSTEM FOR HIGH-VALUE ARMY AVIATION COMPONENTS

by B. Rosenman and D. Hoekstra

Final Report
USASMC Project Number 42-64S
October 1964

Advanced Logistics Research Office
UNITED STATES ARMY
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ABSTRACT

This report describes a system for the management of high value aircraft reparable components (engines, transmissions, gear boxes, etc.) which has been developed for the U.S. Army Aviation Materiel Command by the Advanced Logistics Research Office, Frankford Arsenal. The system was devised as a result of an in-house operations research study performed by that office under U.S. Army Supply and Maintenance Command sponsorship as part of the OSD Aviation Materiel Management Improvement Program.

The system is based upon the calculation, first, of a long-term Desired Inventory Level, which is the number of spares needed to provide some given degree of customer satisfaction, expressed in terms of the average length of time he has to wait for a serviceable replacement spare. The long-term Desired Inventory Level is calculated on the assumption that product improvements have been realized on the item, that its mandatory Time-Between-Overhauls has been extended as far as is feasible, and that pipeline times (repair, overhaul, shipment, etc.) have reached desired standard levels.

The current spares assets are then used, along with current values of failure rates, Time-Between-Overhauls, pipeline times, etc., to calculate what the average customer waiting time would be under an optimal method of allocating spares among Inventory Control Point assets and geographically-dispersed user activities. If this waiting time (which is the minimum waiting time that can be achieved with a given number of spares) is too long, the commodity manager may then consider remedial actions such as use of premium transportation, increasing Time-Between-Overhaul times, expedited overhaul and increasing the amount of local repair, if possible, in order to improve customer service. If these actions can still not bring customer waiting times down to desired levels, he may then consider new procurement to increase the number of spares in the system. Any new procurement, however, must be considered in the light of the long-term Desired Inventory Level, since total spares in the system should not ordinarily exceed that level.

Other features of the system include the use of the Actuarial Method, now in use in the U.S. Air Force, for forecasting time-change and premature removals; the use of exponentially-smoothed tracking methods for discerning significant short-term deviations between forecast (or standard) and actual program factors, removal rates, pipeline times, etc.; and the use of a "push-down" method of replenishing the spares inventory pools of the user areas. The system will use the Army Equipment Record System (TAERS) transactions, rather than supply transactions, as its basic input data.

FOREWORD

On 17 August 1962, the Hon. Thomas D. Morris, Assistant Secretary of Defense (Installations and Logistics) initiated the Aviation Materiel Management Improvement Program (AMMIP) and directed the Army, Navy and Air Force to implement certain management improvement actions in a number of problem areas.* On 15 November 1962 the U.S. Army Materiel Command established an Ad Hoc Group to develop and implement the program for the Army. On 17 May 1963, this Group was dissolved and the U.S. Army Supply and Maintenance Command was directed to take on the responsibility for implementing the schedule of actions which had been drawn up.

As work advanced on the improvement actions, it became evident that supply control methods and related procedures for high-value aircraft components posed a problem on which additional technical assistance was required. The Advanced Logistics Research Office, Frankford Arsenal, was asked to provide such assistance under USASMC Project No. 42-64S, established on 11 December 1963. Target date for completion of this in-house project was 1 July 1964; this date was met.

This report describes the results of the Frankford Arsenal study and contains the initial recommendations for the management of the high-value aircraft components. The concepts of the recommended system have been accepted by the U.S. Army Aviation Materiel Command. However, where the recommendations touch upon a number of important policy areas, it is expected that subsequent discussion at the Department of the Army level may result in some modifications to the system as described in this report.

Throughout the course of this study, personnel of the U.S. Army Aviation Materiel Command have provided ideas and assistance without which a satisfactory system could not have been developed. The number of people involved is too large to permit naming them individually. Their cooperation and help are gratefully acknowledged.

A good deal of assistance was also provided by personnel at the various Army installations visited, by commercial facilities, in particular Bell Aircraft and United Air Lines, and by personnel of the U.S. Air Force Logistics Command and U.S. Navy Bureau of Naval Weapons. Due acknowledgement is made of their contributions.

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*Mr. Morris' Memorandum establishing the program is reproduced in Appendix A.

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CHAPTER 1

INTRODUCTION

This report describes a system for the management of certain high value reparable aircraft components, namely engines, rotors, gear boxes, and the like. The system was developed around a number of guide lines laid down by the Office of the Assistant Secretary of Defense (Installations and Logistics) in his directive of 17 August 1962 establishing the Aviation Materiel Management Improvement Program (AMMIP).

Those AMMIP guide lines dealing with actions to be taken on this class of items were translated by the U.S. Army Supply and Maintenance Command (USASMC) into the following set of study objectives:

(1) Develop a world-wide inventory model adequate for managing the total inventory of these items, regardless of their location.

(2) Devise supply control procedures and formats utilizing the world-wide model as the basis, for requirements determinations, procurement decisions, and overhaul planning.

(3) Develop budget and financial inventory accounting (FIA) procedures and formats compatible with the revised supply control study method.

(4) Consider the feasibility of a "push-down" system of replenishment of users' stocks of spares, under which a report of a field removal automatically triggers a replenishment shipment without the need for requisitioning.

(5) Consider the data from the Army Equipment Record System (TAERS) as the prime source of information by which the system will be managed.

The aircraft engines, transmissions, gearboxes, etc. under consideration form a special class of items. They are the very expensive components in the AVCOM* inventory ranging in unit price from $164 to over $60,000 each, and as a group representing an investment of half a billion dollars.

It is significant that this represents 77% of the total AVCOM dollar value inventory even though only 174 different items are involved.

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*U.S. Army Aviation Materiel Command

Demand rates are low, seldom exceeding a few hundred per year world-wide.

There is essentially no limit to the number of times they can be overhauled and put back into service which gives them virtually unlimited life. There is no attrition to speak of; an item once in the system keeps on cycling between usage and overhaul. This means that nearly all of the procurement of these items takes place during the initial provisioning period and that the supply system is replenished from then on by repair and overhaul.

These items have administratively-established maximum operating hours, called TBO, or Time-Between-Overhaul. When they have logged TBO flying hours since the previous overhaul they must be removed and overhauled. The operating hours log is then re-set to zero. In many cases they do not reach the TBO but fail prematurely. When this happens they may sometimes be repaired instead of overhauled but then the operating hours log is not re-set to zero as is done in the case of overhaul. TBO's start out quite low on a new item for reasons of safety but as the reliability of the item improves they are gradually extended. Finally, all supply and maintenance actions, no matter where in the world-wide system they occur, are reported to AVCOM by serial number under the Army Equipment Record System (TAERS).

Considerable time was spent in analyzing the supply, maintenance, and engineering activities of the U.S. Army Aviation Materiel Command. The Engine Reporting System (ERS), the Aviation Component Reporting System (ACRS), TAERS' transaction data and reports on aircraft status and flying hours were the principal sources of data. In addition field visits were made to Supply and Maintenance activities at the following continental U.S. Army installations.

3rd Echelon

Fort Wadsworth
Fort Bragg
Fort Campbell
Fort Knox
Fort Eustis
Fort Benning

4th Echelon

Atlanta Army Depot
New Cumberland Army Depot
Sharpe Army Depot

5th Echelon

U.S. Army Aeronautical Depot Maintenance Center (ARADMAC)

Data on supply and maintenance organization and practices in the overseas theatres were obtained by means of correspondence and by conversations with AVCOM and USASMC personnel who had visited these areas.

Information on repair and overhaul practices and data related thereto were obtained from a commercial facility, the Bell Aircraft Co., Fort Worth, Texas. The U.S. Air Force Logistics Command and the U.S. Bureau of Naval Weapons also provided a substantial amount of useful data and information. In addition, a visit was made to The Engineering and Maintenance Base of United Airlines at San Francisco, California where very useful data were obtained on performance that could be achieved under tightly controlled conditions.

That the U.S. Army system is far from tightly controlled is evident if one looks, for instance, at the transaction reporting system. Even under the Engine Reporting System, now more than two years old, a number of activities are not reporting at all. The reports that are received contain numerous errors and omissions. And a good number of the reported TBO removals show flying hours which do not even approximately correspond to the mandatory removal times published by AVCOM.

Secondly, the return of unserviceables to the overhaul facility is handled with indifference, resulting in long repair cycle times (from removal for repair or overhaul until restored to serviceable condition). This means relatively poor field availability and excessive investment in spares.

The proposed system is designed to focus management attention and control action on those areas which have the greatest impact upon overall performance.

<u>More accurate and timely knowledge of systems status</u> is the first requirement if the system is to be brought under control. Great amounts of raw data will be produced by the world-wide transaction reporting system (TAERS) and the problem is one of reducing this to meaningful management information and of relating it to the way the system is supposed to operate as a first step to "management by exception."

The operational effectiveness depends to a great extent upon the ability to forecast the number of removals. <u>More accurate removal forecasts</u> lead to better planning and scheduling, reducing the need for protective stock levels.

The number of spares required is directly proportional to the length of the pipelines, currently quite long. Management should therefore be provided with the tools for reducing repair cycle times to technically and economically feasible minimums.

Long-term considerations should guide the procurement actions for the item under consideration. Not only does it take a long time from procurement decision to delivery but also the aircraft population, failure rates and TBO values undergo marked changes over the life cycle of a weapon system.

It is possible to have an adequate number of spares in the system and yet to experience substantial unavailability if the units are stocked in the wrong places. Optimal geographical distribution of available assets is to be achieved as an integral part of the proposed system.

A coordinated effort in these five areas will result in improved operational readiness with fewer spares at less cost.

This report summarizes first, in Chapter 2, the four major elements of the proposed system, namely;

(1) An actuarial method to forecast the levels of activity to be supported.

(2) Automatic (push-type) resupply of geographical areas triggered by the receipt of a TAERS transaction signalling that an item has left the area.

(3) A Supply Control Study, coincident in timing with the budget cycle which relates spares requirements to aircraft readiness requirements at the user level, both for the next fiscal year and for the long term. This Supply Control Study is centered on a world-wide inventory model accounting for differences in levels of activity, pipeline times, military essentiality, etc. in assessing the contribution of individual users to total system activity.

(4) A Monthly Review of actual flying hour programs, rates, pipeline times, and inventory status throughout the system which supplements the annual Supply Control Study in providing short-term management control.

However, considering the present state of the system it is doubtful that these procedures alone will effect much improvement. Decision-making on paper, no matter how well conceived, is not going to make much difference unless it is supplemented by improved field actions. The only solution is to focus a fair amount of high-level management attention specifically on these high-cost aviation components. The proposal calls for the introduction of Regional Aircraft Logistics Managers into the field supply and maintenance activities. Their highly important duties and responsibilities are described in Chapter 3.

In Chapters 4 and 5 the present system is analyzed in greater detail than was possible in this Introduction.

Chapter 6 provides a more detailed account of the key elements in the proposed system. The mathematical basis for the Actuarial Forecast and the Supply Control Study are contained in the several Appendices.

The time period in which this study had to be completed and, indeed, the nature of the problem itself, made it necessary to restrict the scope of its coverage to some extent. Consequently, it will be found that the study does not concern itself with:

(1) items other than aircraft engines and the limited number of the high value reparable components.

(2) the merits of the Army Equipment Record System itself. All that was required in this study was that TAERS data be used as currently described and that no additional reporting be required under the new system.

(3) the formulation of a cost model. Such matters as trade-offs between extra spares vs. premium transportation and repair vs. overhaul are not explicitly treated. The objective was, rather, to develop a system that would permit quantitative assessment of supply performance resulting from employment of a given set of resources without considering at this time the cost impacts of trade-offs between these resources.

(4) the way in which the mandatory Time-Between-Overhaul (TBO) is set. The model accepts whichever values are given, or any projected changes in these values. Inquiry into the way in which these values ought to be determined is left as a matter to be treated in future research.

(5) the way in which the "retail" system, as defined in AR 711-45, is to operate. The system proposed herein assumes that such a

"retail" management system exists and that it can perform the functions described in AR 711-45.

(6) mobilization requirements. These and other one-time, programmed requirements are assumed to be determined in essentially the same way as they are now; once determined, they become part of the input to the Supply Control Study.

CHAPTER 2

SUMMARY OF THE PROPOSED MANAGEMENT AND CONTROL SYSTEM

In the following sections a summary is given of the major elements of the proposed system:

1. An Actuarial Technique for Forecasting Removals.
2. Automatic Re-supply to geographical areas triggered by the receipt of TAERS data instead of MILSTRIP requisitions.
3. An Annual Supply Control Study to develop the procurement budget, overhaul budget, premium transportation requirements and geographical spares allocation pattern.
4. A Monthly Review for short-term management control over pipelines and overhaul schedules.

2.1 FORECASTING OF REMOVALS WITH ACTUARIAL TECHNIQUES

The actuarial forecasting technique was initially developed by insurance actuaries for the U.S. Air Force. It is based on the same actuarial principles as are used by life insurance companies in predicting the number of deaths. A close analogy between deaths of individuals and removals of aircraft time-change components makes it possible to apply this technique in forecasting the number of removals: the chances that an aircraft engine will be removed---either because of reaching its TBO or because of a premature failure---depend on its "age."*

The actuarial technique requires first that the chances of survival at a given age be measured or estimated, the "mortality table" in insurance terminology. The age composition of the population and, in the case of aircraft components, the flying hour program, then enable us to compute the number of deaths (removals) to be expected. The result might be, for example, that 680 removals of the T53 engine are expected next year.

*hours flown since last overhaul

The U.S. Air Force has used the Actuarial Forecasts for a number of years. An impression may be gained of how good these forecasts really are from the data exhibited in Table I, which shows actual and forecasted removals of different model engines during calendar year 1963, along with the error percentage and the year in which the engine was introduced into the system.

It is expected that using the actuarial approach will greatly improve the accuracy of forecasts compared to projecting requirements based on the number of issues during the previous year. However, because of its complication it is the intention to conduct a test on a few selected items before deciding to replace the conventional projections by actuarial forecasts.

2.2 AUTOMATIC RE-SUPPLY TO GEOGRAPHICAL AREAS

The concept of automatic re-supply was developed in response to the need for greater emphasis on returning unserviceable items and on accurate reporting of transactions under TAERS. However, since the area of responsibilities and authority of AVCOM in relation to the Field Commander is a controversial one, it may not be possible to fully implement the concepts described in this section from the outset. However, we believe that the simplicity of automatic re-supply can contribute in an important way to the success of the system and should be given serious consideration.

Under automatic re-supply the responsibilities of the Field Commander are essentially unchanged; he retains complete control over the transportation, supply, and maintenance actions on the items under his custody. However, the size of the pool of items under his custody is fixed: whenever an item is removed from an aircraft and is sent back for overhaul (reported via DA 2410 or 2410-1 under TAERS), a serviceable replacement is immediately sent by the NICP to the stock of the area. The only way to obtain a serviceable item except for a modification in the authorized Area Inventory Level is to return an unserviceable. One might say that the TAERS transaction report takes the place of the MILSTRIP requisition, but only in the dealings between the Field Commanders and the NICP; MILSTRIP still serves the areas internally.

The NICP, knowing that an item has left a certain geographical area, is responsible for taking instantaneous replenishment action without waiting for a requisition. But, in addition, it is visualized that the NICP will play

TABLE I

ACTUARIAL FORECASTS - USAF - CY 1963

Engine	Actual Number of Removals	Forecasted Number of Removals	% Error	Year Introduced
J57-43	1107	1338	21	'57
J57-59/C-135	74	84	14	'61
J57-59/KC-135	1058	971	9	'58
J60-5	92	91	1	'61
J69-25	5997	5506	9	'59
J57-19W	366	357	2	'59
T41-9	406	428	5	'58
T53-1	106	95	12	'57
T56-7	267	230	16	'58
TF33-3	646	630	2	'60
J65-7D	65	60	8	'62
J79-3B	110	110	0	'62

an increasing role in the process of determining how a given number of spares available in the system totally will be distributed between the different geographical areas. As the quality of the data collected and processed under TAERS is improved, AVCOM will be in a position to analyze the needs of the different areas in an objective manner, based on factual information concerning removal rates, re-supply times and utilization of local repair. AVCOM would not normally override the Field Commander in deciding on authorized Area Inventory Levels, but unresolved differences may arise if the system is seriously understocked. Such differences would be referred to the Department of the Army according to AR 711-45.*

The most important advantages to be gained from this approach are that it will encourage speedy local repair action or immediate evacuation of unserviceable items that cannot be repaired in the area and rapid transportation of serviceable items available in the area to removing organizations. It should help to stimulate complete and accurate transaction reporting.

2.3 THE SUPPLY CONTROL STUDY

The proposed Supply Control Study differs in many ways from the procedure now in use. Considering the main purposes of the new Supply Control Study, which are to establish the procurement and overhaul budgets and to arrive at an initial allocation of available spares over the areas, execution of the complete study cycle every quarter is quite unnecessary. Conditions do not change that rapidly and it is therefore recommended to do the Supply Control Study only once a year, to coincide with the budget cycle, or when significant changes in program factors take place.

Currently, requirements are forecasted from historical issue rates. It is the intention to use the removal rates forecasted by the actuarial technique for this purpose if the real-life tests to be conducted in parallel with the conventional procedure prove them to be superior.

The proposed Supply Control Study employs a novel approach in measuring the supply performance of the system. With aircraft widely dispersed throughout the world, a spare component cannot always be immediately available to replace a component which has to be removed from a plane for one reason or

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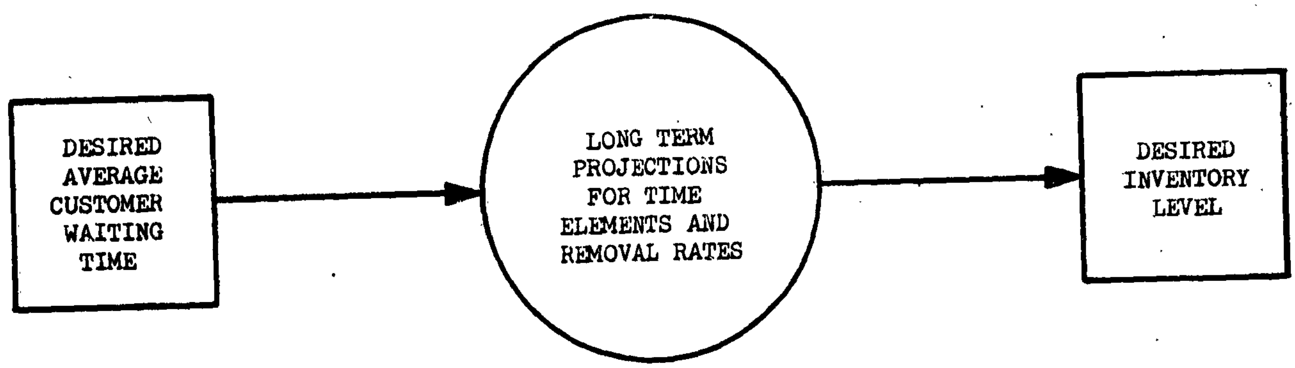
*AR 711-45 established policies and responsibilities for the management of selected aviation reparable components including engines.

COMPUTATIONS IN THE
SUPPLY CONTROL STUDY

LONG RANGE PORTION



NEXT FISCAL YEAR PORTION

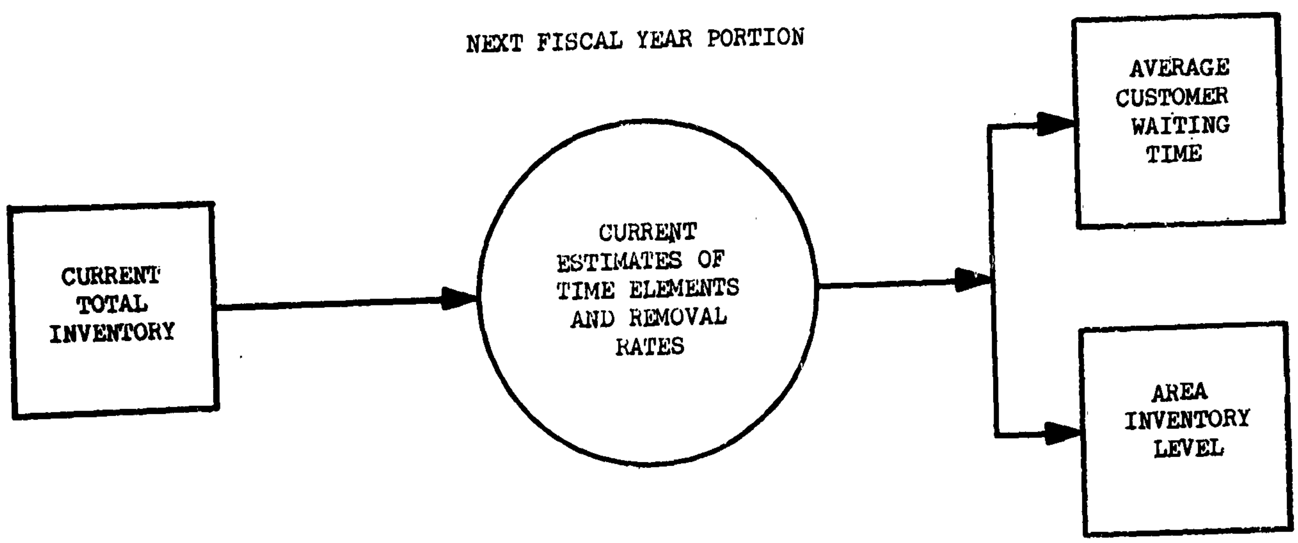


Figure 2.1

COMPUTER OUTPUTS + JUDGEMENTS = <u>DECISIONS</u>

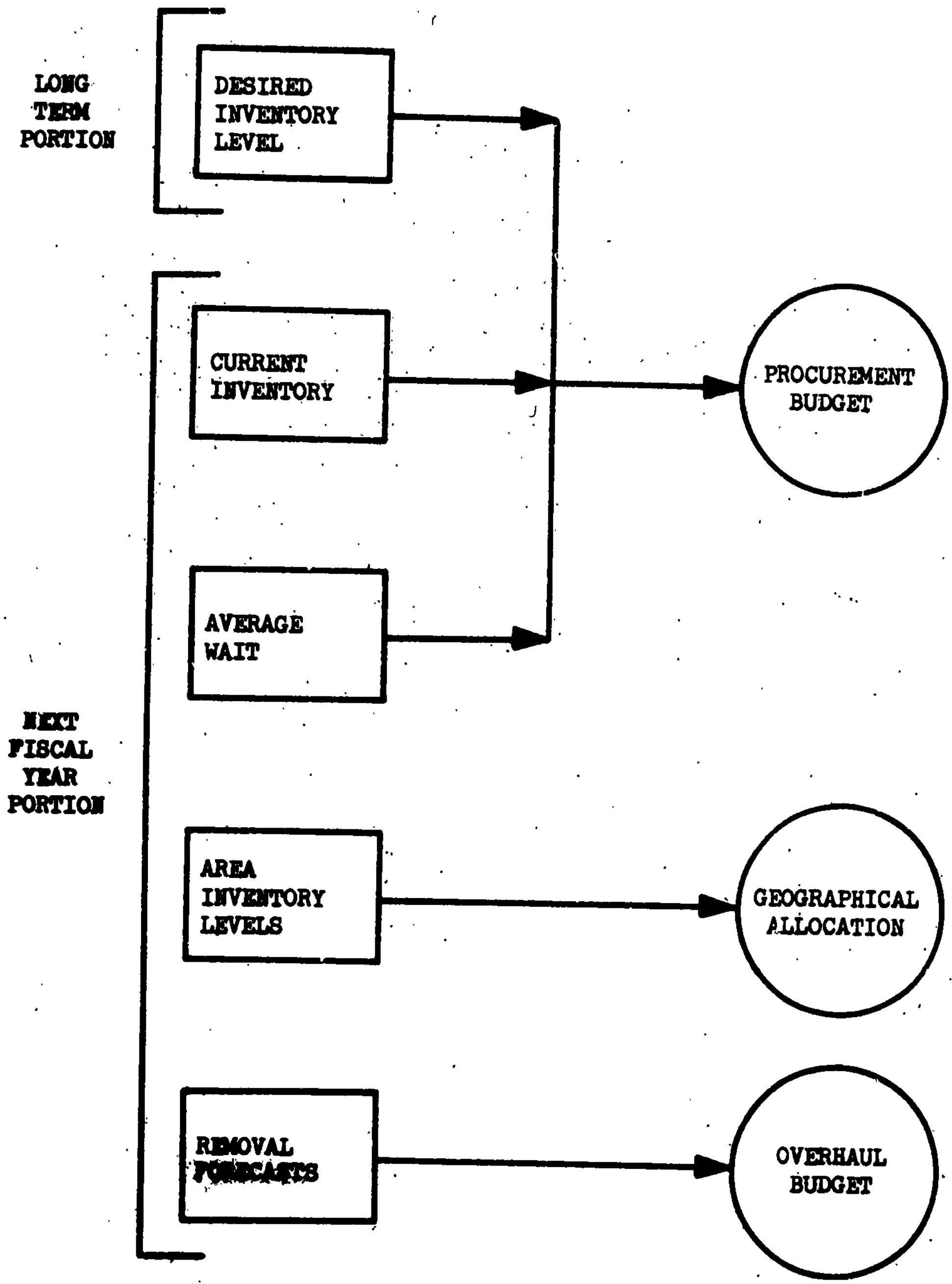


Figure 2.2

another. At times a shortage of UH-1 engines will develop in Japan, for instance, which means that removing organizations have to wait for a replacement item. The ability to support a certain state of readiness of the aircraft population depends on how often engine shortages develop, how long they last, and how many aircraft are grounded as the result. The average time a removing organization has to wait before receiving a replacement engine after removing one from an aircraft is the correct yardstick to measure the supply performance of the system. The zero waiting times when a replacement is on hand in the area are counted in this average wait. The use of the average customer wait as a practical tool in the Supply Control Study is made possible by the availability of computational procedures for estimating it by geographical area based on removal rates, pipeline times, etc. The analysis is thus extended beyond the customary NICP level to provide insight into what happens at the field level.

The Supply Control Study consists of two parts: the long-term portion and the next fiscal year portion, as illustrated in Figure 2.1. The purpose of the long-term portion is to establish the Desired Inventory Level, or the number of spares in the system required to insure a satisfactory customer waiting time in the long run.

The conditions to be considered in this long-run portion are those expected after the necessary product improvement has taken place and the TBO has been extended accordingly, after the time elements of the repair cycle are brought under tighter control and after the entire end-item population has been fielded.

The purpose of the next fiscal year portion is to decide how the currently available spares should be distributed over the different geographical areas and what is the shortest average customer wait that can currently be obtained for the whole system. If this level of customer service is unacceptable, the Commodity Manager or Analyst may investigate the possibilities of lengthening the TBO, using premium transportation, speeding up the overhaul rate, etc., to the extent possible and recompute the Area Inventory Levels and resulting average customer wait.

Figure 2.2 shows schematically how the Analyst compares the Desired Inventory Level with the Current Inventory, considering the current average Customer Wait to arrive at a procurement decision. Procurement should not carry the number of spares beyond the Desired Inventory Level if at all possible or else excesses will develop later. The computed Area Inventory Levels form the basis for determining which area should have how many spares, and the removal rate forecasted by the actuarial method is transformed into the Overhaul Budget.

2.4 THE MONTHLY REVIEW

This computer-generated review of systems status and performance is the major working tool of the Commodity Manager. It makes it possible to separate the annual Supply Control Study with its longer-range considerations from short-term management over pipelines and overhaul schedules. The Monthly Review consists of five sections:

1. Program Factors by Area

   number of aircraft
   flying hours
   average customer wait

2. Rates such as:

   removals
   evacuations
   repairs
   overhauls
   procurements

3. Time Elements such as:

   awaiting shipment
   in-area repair cycle
   transportation
   repair
   overhaul

4. Inventory Status covering:

   installed serviceables
   uninstalled serviceables
   serviceables in transit
   unserviceables on hand
   unserviceables in transit
   in repair

in overhaul
due-in from procurement

5. Next Quarter's Forecasts consisting of:

next quarter's arrivals for overhaul
NICP serviceables on hand after 3 months

Where applicable two sides of the picture will be shown: on the one side what is actually happening as characterized by the current month, the moving average of a number of preceding months, or a year-to-date figure, and on the other side what is supposed to happen as measured by the forecast, budget, or standard established. This will eventually lead to a system of "management by exception" where only significant deviations requiring management attention are reviewed. In some cases the situation may have changed so drastically since the previous Supply Control Study that a new Supply Control Study outside the normal budget cycle is indicated.

CHAPTER 3

REGIONAL AIRCRAFT LOGISTICS MANAGERS

One of the most notable finding of this study is the apparent laxity in the management of these items throughout the supply and maintenance system. This, of course, is a matter of great concern, for no matter what the theoretical advantages of the proposed concepts may be, they will come to naught if the environment in which they are applied is one in which even the most elementary controls are lacking. The basic tools for control are present; what is lacking is an effective means of assuring that they are applied. Experience indicates that measures such as promulgation of additional Army Regulations, directives, inspections and the like can be only partially effective. We believe that special measures are required if significant improvement in the management of these items is to be achieved and that the expenditure of extra effort and resources is more than justified by the great dollar impact of these items.

It is recommended, therefore, that Field Commanders appoint high level Regional Aircraft Logistics Managers, whose major duties would be to:

1. police the reporting system

2. speed up the return of unserviceables

3. assure the rapid delivery of available serviceables to removing organizations

4. assure full exploitation of local repair facilities within the Field Commander's Area

5. serve as the information link between AVCOM and the field

We do not visualize the Regional Aircraft Logistics Manager as an operating official or as a supervisor of an operating organization but, rather, as a "free-lance" staff officer reporting directly to the Field Commander. He should spend most of his time with the field supply and maintenance activities and he should have free access to personnel and records at all levels. It is not necessary that he have directive authority, for he would act as a motivator, educator, trouble shooter, expediter, organizer, consultant, etc. Difficulties that come to his attention should be corrected at the local activity level in all possible cases and his activities should even include on-the-spot informal training when deficiencies in control are discerned. The emphasis in the activities of the Regional Aircraft Logistics Manager should, in other words, be on the building of an effective management and control system from the bottom up rather than on attempting to legislate a control system from the top down.

The activities of the Regional Aircraft Logistics Manager with respect to each of his major responsibilities will now be discussed in more detail.

1. POLICING THE TRANSACTION REPORTING SYSTEM: It is not intended that DA 2410's and DA 2410-1's pass through the Regional Aircraft Logistics Manager. Rather, it is intended that he evaluate their quality by sampling methods during his visits to the maintenance and supply activities. In addition, it is expected that he will be notified by AVCOM on a continuous basis of erroneous, missing and questionable transactions as a result of their daily processing of these TAERS transactions. The combined intelligence obtained from his own observations and from the AVCOM feed-back should provide him with a basis for detecting patterns of deficiencies and, then, for instituting the necessary informal correctional measures.

2. SPEEDING UP THE RETURN OF UNSERVICEABLES: Again, his sources of information would be the continuing visits to supply and maintenance activities in his area and the daily TAERS transaction edit at AVCOM. The AVCOM reporting system should also provide data on how the performance in this respect compares to that of other Field Commands.

It can be expected, also, that some slippages in the return of unserviceable are not the fault of the originating Command. Such things as unavailability of the desired mode of transportation, shortages of transportation funds, etc. may at times be the cause. In such cases, the Regional Aircraft Logistics Manager would be the logical one to turn to for rapid resolution of the problem.

3. ASSURING THE RAPID DELIVERY OF AVAILABLE SERVICEABLES TO REMOVING ORGANIZATIONS: As indicated in Chapter 1, it has been assumed in the development of these recommendations that the so-called "retail" management system of AR 711-45 exists and that it functions in an effective manner. Thus, the performance of the AVCOM "wholesale" system could properly be judged on the basis of its success in providing serviceables to the interface between the two systems. This, indeed, is the approach taken in the proposed system where it is assumed that a serviceable spare anywhere in the Field Commander's area is available to maintenance activities in the area almost immediately.

However, since the AVCOM forecasts and supply decisions are based in part on what is expected to happen within the "retail" areas, it is necessary that we concern ourselves at least in a general way with the internal activities of those areas. The number of spares needed in a particular Command area depends not only on the re-supply time values that link it to the "wholesale" system, but also on its own internal pipeline times. Thus, such factors as the fraction of removals in the area that are repaired locally, the local repair time and the time required to get a serviceable spare from the area's stockage point to the maintenance activities all have an important effect on the supply performance which the Field Commander can obtain from his pool of spares. The conditions noted during the course of this study suggest that there is considerable room for improvement in the conduct of these activities and, again, we feel that special management effort will have to be exerted in order to achieve such improvements. The special characteristics of the Regional Aircraft Logistics Manager, as we visualize them, would suit him ideally for this task.

4. EFFECTING FULL EXPLOITATION OF LOCAL REPAIR FACILITIES: Local repair facilities, if properly used, can reduce pipeline times considerably especially for the overseas Command areas. The principal reasons for not using these local facilities seem to be shortages of skilled personnel, lack of parts, lack of specialized tools and test equipment, and, frequently, lack of authorization to do the work.

The building of a more effective local repair capability is, of course, going to require some time. We believe, however, that the Regional Aircraft Logistics Manager can make substantial contributions to the building of such a capability. His direct contacts with AVCOM can do much to straighten out the log-jams that so often result from inconsistencies between supply and maintenance policies. His familiarity with the facilities in his area should enable him to recommend correctional programs that will, in time, result in better utilization of the resources available.

5. SERVING AS THE INFORMATION LINK BETWEEN THE FIELD COMMANDS AND AVCOM: This is probably one of the most vital roles that the Regional Aircraft Logistics Manager will be called on to play. It is conceivable that, in time, some of the tasks described above will become less important as improvements are made and as personnel at all levels become more accustomed to the newer procedures. The need for a rapid and intelligent information link that works in both directions, however, will never diminish. Indeed, the existence of such an information link is a fundamental necessity under the Army concept of inter-dependent but separately managed "wholesale" and "retail" systems.

The Regional Aircraft Logistics Manager would have, first, a most important duty in keeping AVCOM informed of those instances when slippages in the "wholesale" system are causing difficulties within the Field Commander's area. Deviations from pipeline time standards in processing resupply transactions and in shipping serviceables to the area, shortages of parts required to support local repair programs, etc., can be expected to occur in a system so widely dispersed and so complex. The Command would certainly benefit from the services of knowledgeable and experienced Regional Aircraft Logistics Managers who have direct access to AVCOM and who know exactly what channels to take to solve these problems quickly.

The information channel in the other direction is at least equally important. For example, Regional Aircraft Logistics Managers will visit AVCOM at the time of the annual Supply Control studies so that AVCOM can take advantage of their familiarity with the conditions in their areas. This knowledge will be of great value to the AVCOM engineers and Commodity Analysts in forecasting operational programs, removals, local repair possibilities and pipeline times. The Regional Aircraft Logistics Managers would, then, be in a position to participate directly in the development of system requirements and in the setting of the Area Inventory Levels. They will greatly benefit from this participation in the planning of the supply and maintenance programs of their respective Command areas. Furthermore, it will provide them with a sound basis for determining when changes in local conditions are significant enough to warrant changes in AVCOM plans. This could be brought to the attention of the proper AVCOM personnel very quickly so that necessary adjustments can be made before the system drifts out of control.

The duties of the Regional Aircraft Logistics Manager are, as can be seen, extremely broad in scope. The qualifications required for successful performance of these duties should, therefore, be very high. We visualize the jobs being filled either by officers at the full Colonel level or by civilians at the GS-15 grade. They should have wide-ranging experience in Army aviation, preferably with some engineering background, although this last attribute need not be a prerequisite. They should have demonstrated ability to do high level staff work. On the personal side, they should be highly energetic and imaginative people, with well-developed persuasive talents; such qualities as patience, tact and persistence would, of course, be enormously valuable. As indicated above, they should have direct access to the Area Commander and to all levels of personnel throughout the Command area. They must also have direct access to AVCOM and the freedom to communicate with whatever levels within AVCOM as are necessary to obtain rapid action.

TABLE II

Aircraft Type & Model Number	No. of Different Engines Applicable (Different Model Nos.)	No. of Other Components Applicable (Prime FSN's)	No. of Other Components Applicable (Sub. FSN's)
CH-34	5	7	38
CH-37	2	15	65
CH-47	2	37	96
CV-2	3	1	-
OV-1	2	1	1
UH-1	7	10	27
UH-19	6	8	39
CH-21	2	8	96
OH-13	7	5	7
OH-23	5	8	18
MQM57A	1		
O-1	3	1	1
U-1	3	3	4
U-6	5	1	2
U-7	2	-	-
U-8	8	-	-
U-9	6	-	-
	69	105	394

TOTAL FEDERAL STOCK NUMBERS = 568

CHAPTER 4

DESCRIPTION OF THE CURRENT SUPPLY AND MAINTENANCE SYSTEM FOR HIGH-VALUE AIRCRAFT COMPONENTS

4.1 CHARACTERISTICS OF THE ITEMS

Before describing the current supply and maintenance system for these items and what we observed in the operation of the system, it is necessary to describe the items' characteristics, for these are what dictate, to a great extent, the concepts that must be applied to their management. These characteristics are summarized as follows:

They are few in number: The items considered in this study are the engines, gearboxes, transmissions, rotors, propellor assemblies, etc. used on Army aircraft. There are very few different line items involved,* as indicated in Table II.

They are very expensive: Unit costs of these items range from $164 for the Fan Drive Shaft Assembly on the CH-47 to over $60,000 for some of the newer Gas Turbine Engines. While they are few in number (less than 1% of all AVCOM items), there is $500,000,000 invested in the inventory of these items. This is 77% of the total AVCOM inventory dollar-value. Over $32,000,000 was spent on the overhaul of these items in FY 1964.

They are almost all Time-Between-Overhaul (TBO) items: These items have administratively-established maximum operating times --- that is, when they have logged some given number of flying hours, they must be removed and overhauled. After being overhauled according to prescribed standards, their operating hours log is re-set to zero and they are, for all intents and purposes, the same as a brand-new item. They can, of course, experience failures before reaching TBO time. When this happens, they may, depending upon their condition and the hours already logged, be restored to serviceable condition through repair of the defect with their log of operating hours remaining the same, or they may be completely overhauled, with the operating time being re-set to zero.

*A complete listing of these items is given in AVCOM Supply Letter No. 28-64 dated 16 March 1964.

They have "unlimited" life: Very few of these items leave the system during the life of the aircraft itself. There is essentially no limit to the number of times they can be overhauled and put back in service. Whatever attrition does occur is usually compensated for by aircraft attrition and by product improvement of those remaining. Thus, nearly all of the procurement of these items takes place during the initial provisioning period. The supply system maintains itself from then on by repair and overhaul.

Demand rates are low: The number of removals requiring a serviceable spare is usually low, seldom exceeding several hundred per year. However, a significant characteristic of the system is that these removal rates tend to change over time because failure rates begin to improve and TBO's, which are kept very low initially, are gradually extended as product improvements are incorporated.

They all have serial numbers: All items considered in this study are subject to serial number control under TAERS, i.e., every transaction, change of status, etc. which applies to an individual item such as an engine, no matter where it is located, is supposed to be reported to AVCOM. The availability of this data opens up rather unusual possibilities for the management of these items. On the other hand, if this data is not used for management purposes, the effort expended in the collection, transmission, and processing of this data is largely wasted.

4.2 THE SUPPLY AND MAINTENANCE CYCLE

Most maintenance work on these items is done at 4th and 5th echelon shops. On-aircraft repair may be done at 3rd echelon but, for the most part, when something seriously goes wrong with them or when they have reached TBO they must be removed for repair or overhaul at higher echelons. The majority of removals of these items, whether because the TBO time has been reached or because a premature failure has occurred, are done at 3rd echelon. There are some 80 of these 3rd echelon shops throughout the world and it is to this level that serviceable replacement items must ultimately go. There are approximately twenty 4th echelon shops throughout the world. These 4th echelon shops do a good deal of modification work, and some repair on items other than engines. Overhaul is almost never done at 4th echelon; this requires special authority from AVCOM which is granted in only a few special cases.

Overhaul, then, is done either by the U.S. Army Aviation Aeronautical Depot Maintenance Center (ARADMAC) at Corpus Christi, Texas, or by commercial facilities. It requires a complete tear-down of the item, mandatory replacement of a specified list of parts, stringent inspection of the remainder, and complete operational test of the re-assembled item. The operating hours log of an overhauled item is reset to zero and it is considered as good as new. Overhaul (5th echelon) facilities may in some cases repair rather than overhaul these items, particularly in the case of premature removals that have yet a considerable number of hours to log before reaching TBO. This repair is usually done under the IROAN* concept and the operating hours log of the item remains unchanged.

When an item reaches TBO it is usually turned over to the supply organization in the field and shipped back to the appropriate CONUS depot. There it remains until scheduled for overhaul by AVCOM.** Premature removals are supposed to be examined by 4th echelon personnel and the decision is then made as to whether they can be repaired at 4th echelon. If this can be done in a short time (say, 2 or 3 days) they may be repaired and returned to the user and re-installed on the aircraft. If not, they would be returned to stock when repaired. In either case, the hours logged on the item remain unchanged.

One important point must be made here. In the case of CONUS 4th echelon repair, return to stock usually means that the item is picked up on the supply accounts of the CONUS depot when repair is completed. This stock is under direct NICP control.*** In the case of 4th echelon repair done overseas, however, the repaired item remains in the overseas area and does not come under direct NICP control.

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*Inspect and Repair Only As Necessary.

**In some cases when supply is critical, shipment direct to the overhaul facility may be authorized by AVCOM.

***One exception occurs when the 4th echelon is operating a Direct Exchange System for the item under which the user gets a serviceable replacement item from the Direct Exchange pool when he turns in the unserviceable for repair. The repaired item, in such cases, remains in the DX pool and would not be under NICP control.

If the 4th echelon maintenance activity decides that the item cannot be repaired at their level, or that the Maintenance Allocation Chart does not authorize them to repair it, the item is turned over to the supply organization. In the case of CONUS, the supply organization is the CONUS Depot and the unserviceable item thus passes into the control of the AVCOM NICP. Here it remains until scheduled by AVCOM for shipment to a 5th echelon facility for repair or overhaul. In the case of overseas 4th echelon units, the unserviceable item is returned to a CONUS Depot and passes into the control of the AVCOM NICP where it remains until scheduled for 5th echelon repair or overhaul. The unserviceable items may, however, be inpected by the Depot maintenance activity and some may be repaired and become serviceable (although not zero time) items under AVCOM NICP control.

Serviceable stocks of these items are held under NICP control at four depots in CONUS. These are the Atlanta (Ga.), New Cumberland (Pa.), Fort Worth (Tex.) and Sharpe (Calif.) Army Depots. Requisitions for serviceable spares from the field are sent directly to AVCOM, St. Louis, who then directs shipment from the appropriate depot. No movement of stock from these depots can be made except under AVCOM direction. Serviceable spares of these items are also held at 4th echelon supply activities overseas and at many, but by no means all, 3rd echelon supply activities. Whether or not the activity carries serviceable spares in stock depends on the removal rate it has to support. Normally AR 711-16 criteria are used to determine this. Organizations that stock these high value items compute Requisitioning Objectives under AR 711-16 criteria and requisition replacements when their on-hand and on-order spares drop below that level. AVCOM may decrease these levels when the supply of serviceable spares is critical. "Rapid Service" Transportation may be resorted to (described in AR 710-712 and DA Supply Bulletin 55-35) under such circumstances.

4.3 THE PRESENT SUPPLY CONTROL STUDY

World-wide requirements for these items are determined at AVCOM by means of supply control studies. These studies are done quarterly. In addition, supply control studies are done if serviceable assets (on hand + due-in) are equal to or less than a Reorder Warning Point. Studies are done generally in accordance with AR 710-45 policies except for the following major differences:

(1) Flying hour program changes and programmed TBO changes are used as program factors in calculating expected demand in each forecast period;

(2) Expected changes in requisitioning objectives of installations below depot level are taken into account. Changes in below-depot requisitioning objectives are calculated from expected changes in aircraft population, flying hours and TBO's;

(3) Assets below depot level are taken into account.

Requirements are forecast by quarter over a 30-month forecast period. The forecasts are made by major theatre (CONUS, Europe and Pacific), then summed by forecast quarter. The following elements are considered:

(1) Safety level - fixed at 60 days' demand for CONUS, 30 days for the other theatres, based on average quarterly recurring demand at depot level over the last 12 months multiplied by ratio of projected flying hours for 1st forecast quarter to average flying hours per quarter over the last 12 months. This quantity is entered as part of the requirement for the 1st forecast quarter.

(2) Authorized mobilization reserve - method of computation is classified information. In any event, this quantity is also entered as part of the requirement for the 1st forecast quarter.

(3) Expected recurring demand - this is computed for each forecast quarter as in (1) above.

(4) Expected non-recurring issues - these are requirements that are known to be one-time issues, such as shipments already scheduled to go to MAP countries, etc. They are known as to quantity and quarter in which they are scheduled to take place and are thus entered in the appropriate forecast quarter.

(5) Expected provisioning issues - these are also known as to quantity and time in which they are to occur since they are scheduled to coincide with new aircraft deliveries.

(6) Expected pipe line changes - the last requisitioning objective for each activity below depot level is known. These are summed for each theatre and a forecast requisitioning objective for each forecast quarter is calculated by multiplying the base period requisitioning objective by the flying hour program factor. The difference between each forecast RO and the base period RO becomes the expected pipe line change for the forecast quarter. Note that these differences may be positive or negative.

Reorder Warning Point: A period of time equivalent to the replenishment lead time is calculated as follows:

(1) Administrative time - 1 month if repair is normally done in a government facility; 3 months if commercial.

(2) Estimated overhaul time - based on previous experience.

(3) Shipping time - 1 month.

Note that procurement lead time is not mentioned. This is because of the fact that requirements normally are expected to be met by overhaul of unserviceable items.

Application of Assets: Serviceable assets are also forecast by quarter, these being the on-hand serviceable assets plus the dues-in from overhaul during each forecast quarter. These assets are subtracted from each corresponding quarterly requirements forecast. If a deficit is found within the Reorder Warning Point period, a replenishment action is initiated. The replenishment quantity is the sum of this deficit and the reorder quantity (the next 2 quarters' requirements if the item's total annual demand is less than $25,000, the next quarter if total demand is $25,000 or more).

Overhaul of on-hand unserviceable assets is initiated for this quantity. If insufficient unserviceable assets are on-hand, a forecast of expected unserviceable returns is made based upon straight averaging of unserviceable returns experience. These are also included in the overhaul schedule to the extent needed.

The data used in the supply control study and in other supply actions have been largely the data generated from operation of the supply system under AR 725-50 and related program data. In 1962, The Engine Reporting System (ERS) was instituted by AVCOM which provided world-wide reporting of individual aircraft engine transactions and status by engine serial number. Data emanating from this system have been used since that time to supplement information received from the AR 725-50 system. In 1964, the ERS reporting concept was extended to the other high value aircraft reparables covered by this study. This was known as the Aircraft Component Reporting System (ACRS). Both ERS and ACRS were superseded by The Army Equipment Record System (TAERS) on 1 July 1964 (see TM 38-750). TAERS, has, however, preserved the reporting concepts and informational content of both the ERS and ACRS.

One of the most important elements of program data used in the Supply Control Study is the forecast of the Flying Hour Program. This is generated at Department of the Army level; it covers, usually, the next 30 months and is received quarterly. Until the start of FY 1965 this was a gross program forecast for each aircraft type without geographical or theatre breakdown. AVCOM has traditionally used aircraft population as a basis for sub-dividing the gross program forecast among the various theatres. However, program forecasts incorporating some degree of theatre break-out are supposed to begin in FY 1965.

Reports of aircraft status and hours flown per aircraft are received monthly by AVCOM on DA 1352 reports. These are furnished by the individual aircraft custodians and are by aircraft serial number. These reports are used by AVCOM as a basis for modifying program forecasts.

CHAPTER 5

OBSERVATIONS ON THE PRESENT SYSTEM

As a result of the detailed fact-finding that was done during visits to the various Army Supply and Maintenance activities and from review of a large volume of data, a number of observations have been made about weaknesses in the present system which are directly related to the overall supply performance of the system. These observations, along with the stated objectives of the study, formed the basis for the design of the system recommended herein. A discussion of these observations follows:

5.1 CONTROL OF THE SYSTEM

The most notable finding has to do with the looseness of control exhibited throughout the system. Some examples follow:

Field Reporting: Reporting of transaction card status data from the field is extremely poor. This was found even with the Engine Reporting System data, which are data collected under a system that is now more than two (2) years old. For example:

(1) A number of activities were not reporting at all. This was particularly true of maintenance activities visited who were of the opinion that the system applied only to supply activities.

(2) Transaction reports contained numerous errors of commission and omission.

All actions beginning with an engine removal were tabulated. There were 2,058 so-called "good" transactions. However, there were 10,000 transactions that had to be rejected for such reasons as:

- No such FSN of component exists.
- Aircraft application not identifiable.
- Model and/or serial number of aircraft or component missing or incorrect
- Organization submitting report could not be identified.

- Reason for removal not identifiable.

- Obvious data error.

Of the 2058 "good" removal actions, 436 represented a complete cycle - i.e., they started with a removal action and they terminated with a transaction reporting completion of repair or overhaul or shipment after completion of repair or overhaul. However, only 50 of these 436 complete cycle cases reported the intervening transactions of shipment to the repair facility and start of the repair action. Data reported under the Army Equipment Reporting System (TAERS) seemed to be about as bad. About 1/2 of the initial group of DA Form 2410's key-punched on the UH-1 aircraft contained gross errors that rendered the data useless.

TBO Discipline: Review of DA 2410 data indicated that something is radically wrong with field observance of the mandatory TBO's published by AVCOM. A sample of 290 removal transactions was reviewed, for example; of these 130 reported the mandatory TBO time as being different from the published figure. Many of these errors appeared to be due to lags in getting revised TBO values published and into the hands of field units. However, a significant number of these transactions reported TBO figures that, according to AVCOM records, had never been broadcast.*

Direct Exchange Pools: This is a relatively minor point but is, nevertheless, indicative of the looseness of control. Direct Exchange pools of spares of these high-value items were found to exist at some maintenance activities at a time when these same items were on the AVCOM "Critical and Controlled Items List." The existence of these pools and transactions affecting them were not reported to AVCOM and these assets were not available to the rest of the system.

5.2 REPAIR CYCLE TIMES

The repair cycle time, which is defined as the total elapsed calendar time from removal of the component until it has been restored to serviceable condition, was examined, using Engine Reporting System data, with the following results.

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*It should be recognized, also, that some of these discrepancies may be pure data errors.

Return of Unserviceables: Return of unserviceables to repair facilities is handled in a very indifferent manner. Data on 424 removal actions covering 5 different engine types showed the following performance on time between engine removal and initiation of shipment of the unserviceables:

Average Time	-	35 days
106 Engines	-	over 50 days
51 Engines	-	over 100 days

Data on actual transportation times were very difficult to obtain because of scarcity of good transactions in the ERS data. Thus, meaningful average transportation times could not be computed. Shown below, however, are some ranges of transportation times found in these data:

Viet Nam to Sharpe	10-76 days
Japan to Fort Worth	9-174 days
Ft. Benning to ARADMAC	3-211 days
Ft. Worth to ARADMAC	1-71 days
Sharpe to ARADMAC	5-61 days

Duration of Overhaul: ARADMAC shop records were used in the tabulation of the elapsed times between introduction of an item into the overhaul line until completion of overhaul, with the following results:

Engine	Quantity Overhauled	Avg Time in Work Days
0-470-11, 11A	566	80
0-335-68	46	93
0-435-238	210	69
T-53-L1A	62	99

Comparable overhaul times were found at Bell Aircraft Company. For example, overhaul records of 84 UH-1A and -1B transmissions showed an average elapsed time of 77 days.

One common complaint of maintenance activities is that much of the delay during overhaul is caused by lack of parts. The following statistics were collected from ARADMAC shop records:

Type of Component Overhauled	Quantity Overhauled	Avge Total Overhaul Time (in work-days)	Avge Time Waiting f/Parts (in work-days)	% of Time Waiting for Parts
Gear Boxes	281	48	30	62.5%
Transmissions	93	72	49	68.0%
Main Rotors	31	33	8	24.2%
Hub Assemblies	14	45	27	60.0%
Clutch & Fan Assy	33	61	45	73.7%
Hydro-Mechanical Clutch Assy	24	55	35	63.6%

Bell Aircraft data showed the average delay awaiting parts in the UH-1 transmission overhauls to be 16 days.

It should be recognized that the "awaiting parts" data were obtained from shop records and that there was no opportunity to check on the validity of the contention that the parts were the actual cause of the total reported delay. Nevertheless, whether or not the data are accepted as fully accurate, they can be accepted as being indicative of a problem area to which continuing attention must be given.

<u>Use of Field Repair Facilities:</u> Very little use is made of existing repair facilities. Many items which now make the full cycle through overhaul could have been repaired at a lower echelon and returned to service that much faster. The 4th echelon facilities in CONUS, in particular, seem to be capable of doing much more extensive repair on these items than they are currently doing. To illustrate this point, ERS data showed that 35% of the T53 Engines shipped to ARADMAC were repaired, rather than overhauled. This includes all engines shipped there, including those that had reached TBO on which overhaul was mandatory.

All of these elements add up to a very long unserviceable cycle time. Cycle times of up to <u>417</u> days were noted. The average, for 239 complete observations, was <u>175</u> days.

5.3 SPARES RATIOS

One significant measure of the efficiency of a support system is the ratio of spares to installed components. Shown below are some examples of spares ratios found on AVCOM engines:

Aircraft Model	No. of Installed Engines	No. of Spare Engines	Spares Ratio
UH-1	853	376	0.44
OV-1	372	181	0.49
H-13	437	638	1.46
H-19	256	348	1.36
H-21	257	375	1.46
H-23	411	381	0.93
H-34	282	300	0.79
H-37	178	167	0.94
O-1	1670	1403	0.84
GRAND TOTAL (All Aircraft Models)	7739	6093	0.79

It is shown here how about 80 spare engines are carried for each 100 installed engines. The grand total spares ratio for the U.S. Air Force, by comparison, is only 40 per 100, and much lower than that on newly procured systems, e.g., new fighters .16 and new cargo planes .25.

These data are shown to bring out the point that there is no value of Spares Ratio that is "correct" or "good" in itself. Spares Ratios must be determined for each component and must include consideration of such factors as failure rates, flying hour programs, ratio of repair to overhaul, pipeline times, degree of customer satisfaction desired, etc. The current methods of supply control do not provide an explicit way of measuring these factors in such a way as to permit a determination of the Spares Ratio that is "correct" for a specific component under a given set of operating conditions. The procedures designed during the course of this study do, however, permit such a determination to be made.

5.4 EQUIPMENT DOWN FOR PARTS (EDP) RATES

Because of the importance of these high-value items and the close management accorded them, very few EDP incidents should be caused by them. Nevertheless, a study recently completed at AVCOM shows:

	No. of EDP Reqns.	No. of EDP Reqns. for Hi-Value Items	No. of EDP Reqns. due to Hi-Value Items
2nd quarter FY 64	1716	165	9.6%
Month of Jan 64	1272	104	8.2%

These data indicate that, despite the high number of spares in the system, the unavailability of these items at the field level where they are needed as replacements for failed items or those that have reached TBO is a real problem area, to be given explicit treatment in the design of the new system.

5.5 FLYING HOUR PROGRAM DATA*

Flying Hour Program data received by AVCOM were reviewed along with actual flying hour data obtained by computer processing of DA Form 1352 Reports that had been submitted to AVCOM by field units. Quarterly Flying Hour Program Forecasts (world-wide) for seven different aircraft have been charted in Figures 5.1 through 5.7 along with the hours actually flown. As can be seen, the cumulative forecasts seems to be consistently over-stated. However, the actual hours flown are rather uniform from quarter to quarter, and it should be possible to devise a smoothing procedure that would forecast the actual hours to be flown with acceptable precision.

*Throughout this section, the identification of the user areas and of the aircraft have been deleted so as to avoid having to classify the data.

ACTUAL VERSUS FORECASTED FLYING HOURS
(Cumulative, World-Wide)

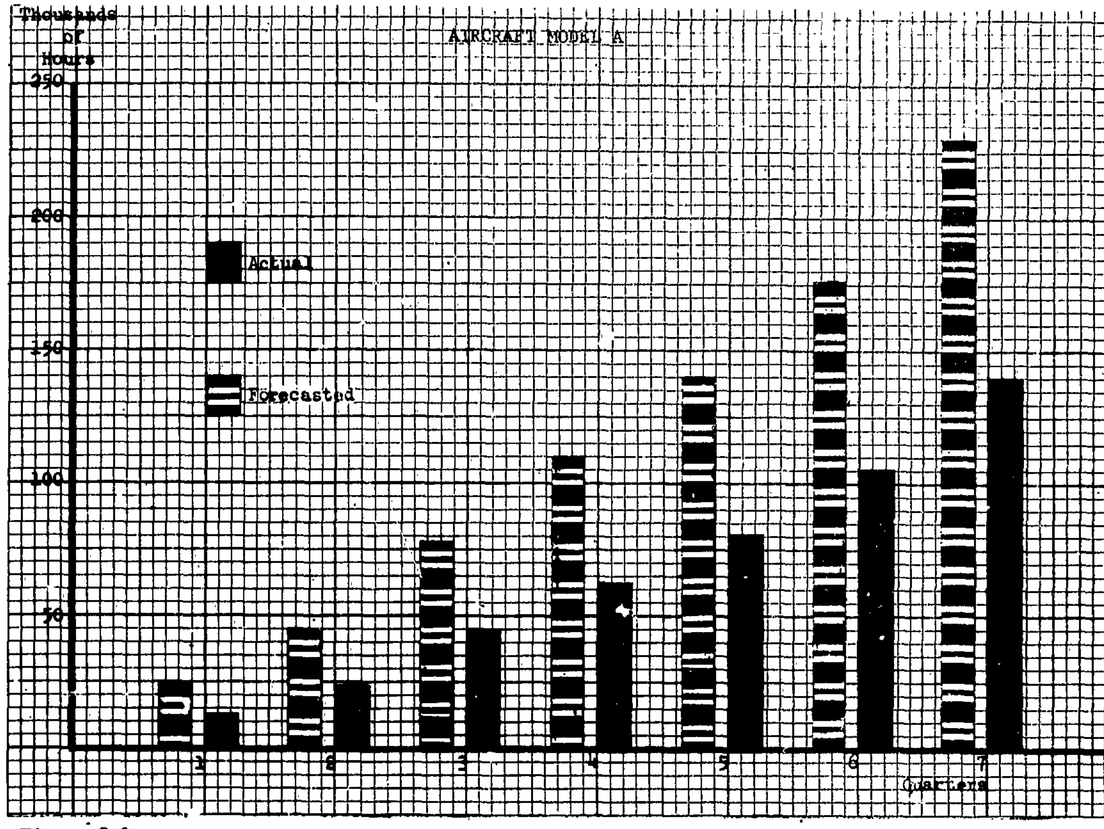


Figure 5.1

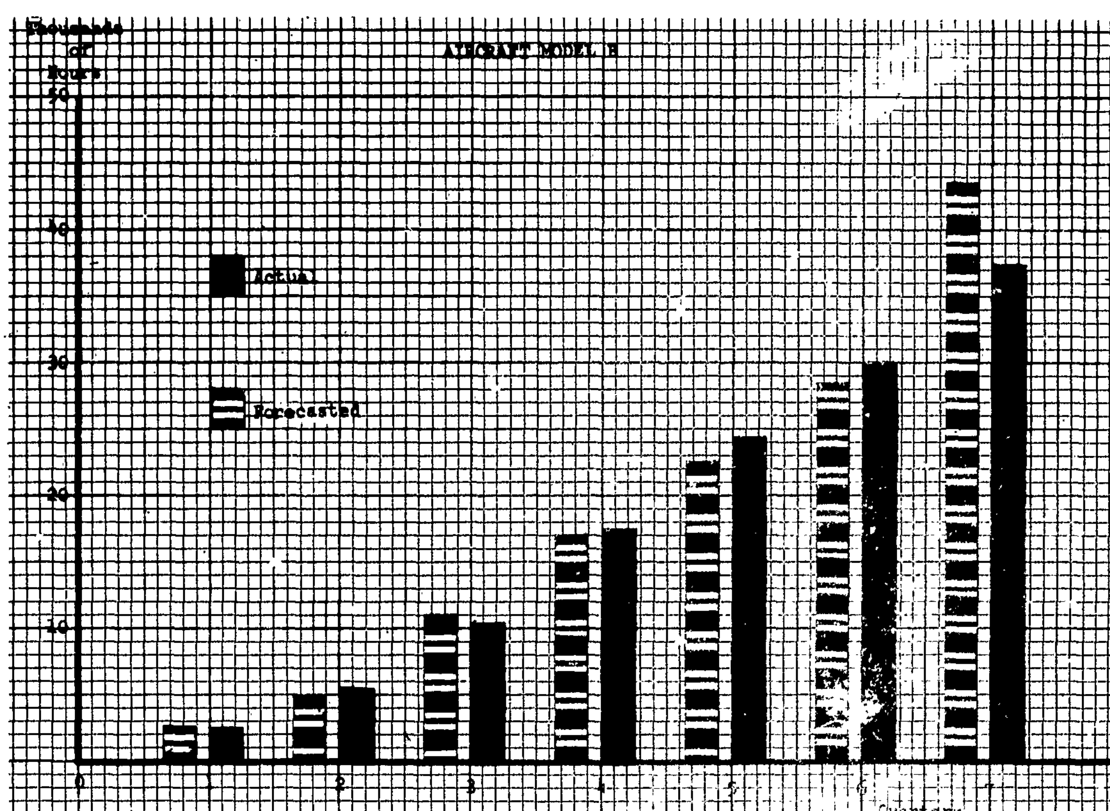


Figure 5.2

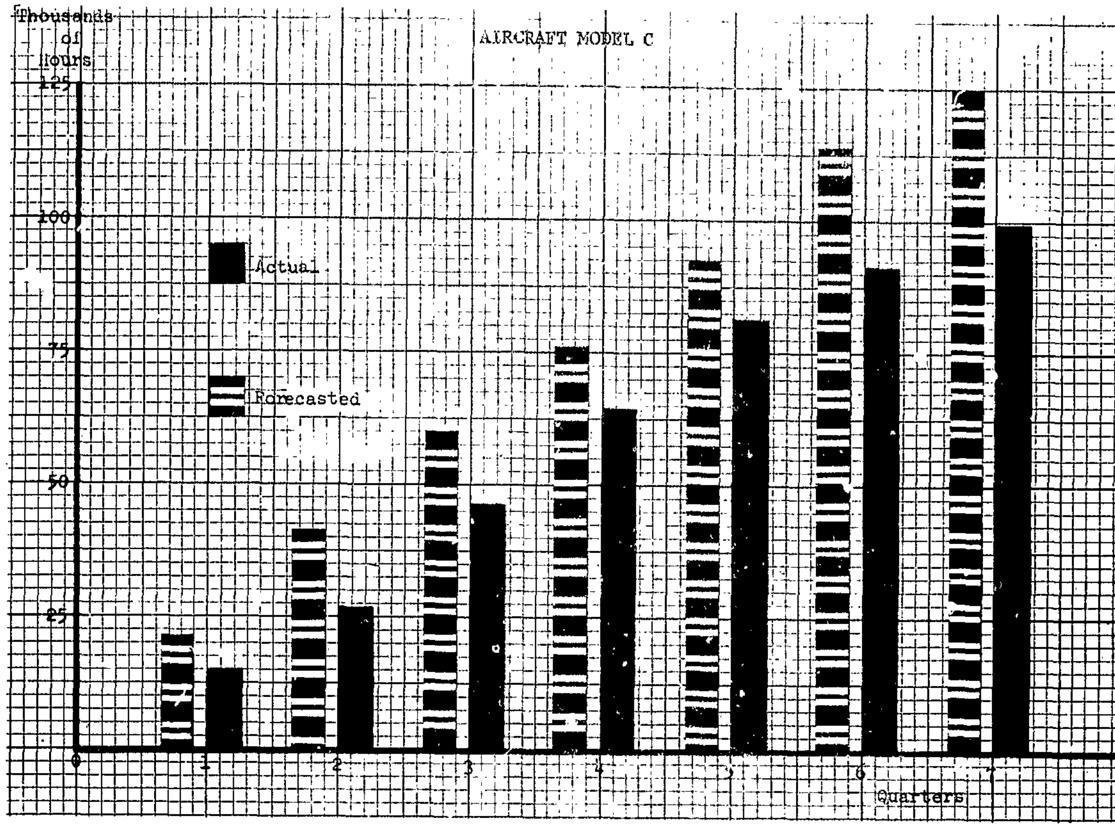


Figure 5.3

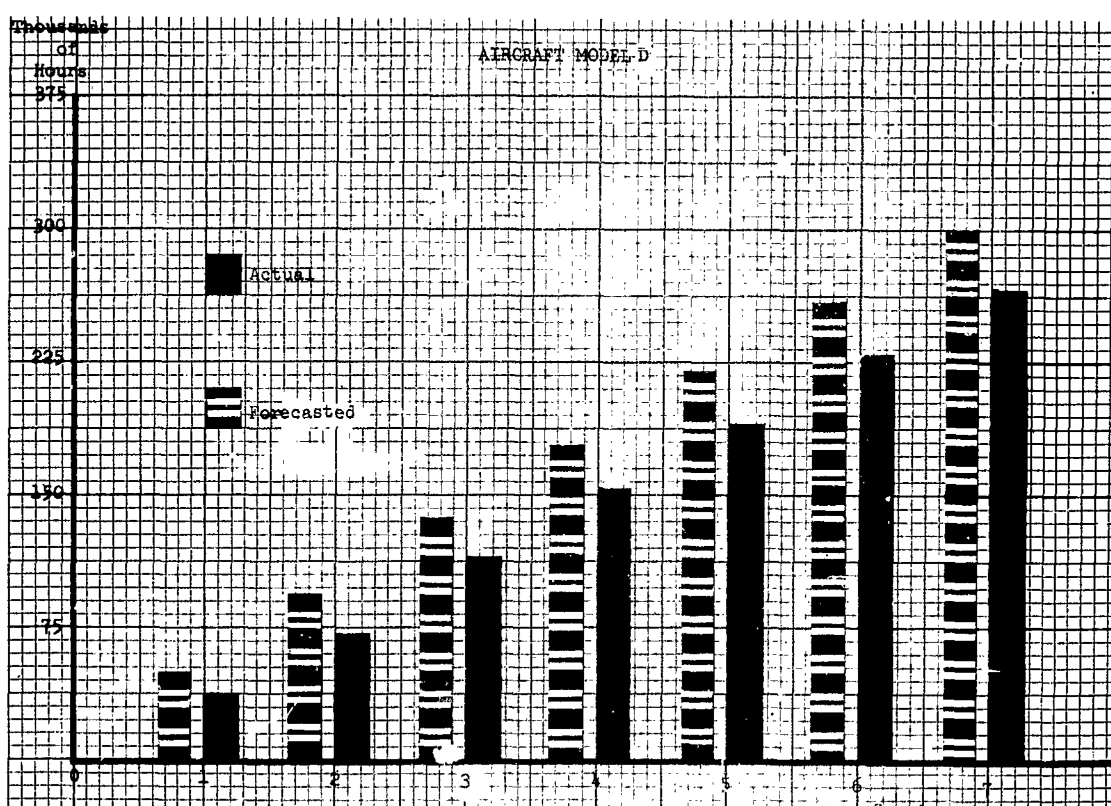


Figure 5.4

..CTUAL VERSUS FORECASTED FLYING HOURS
(Cumulative, World-Wide)

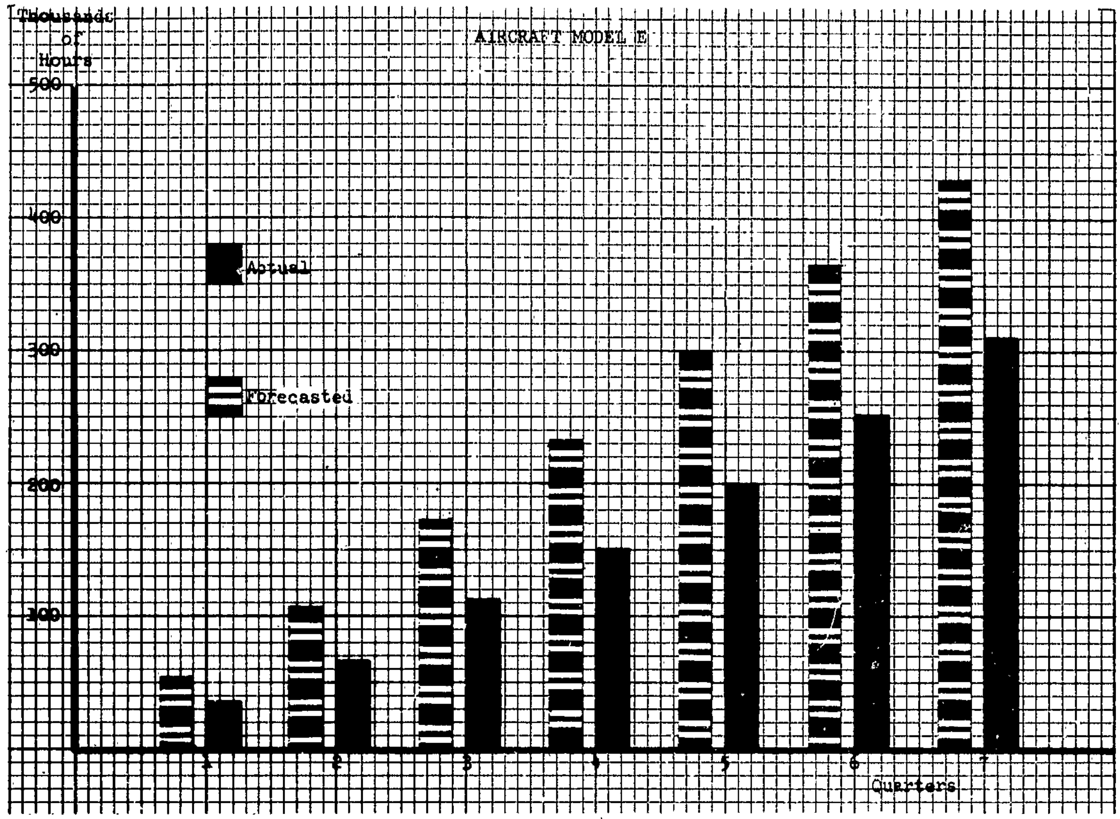


Figure 5.5

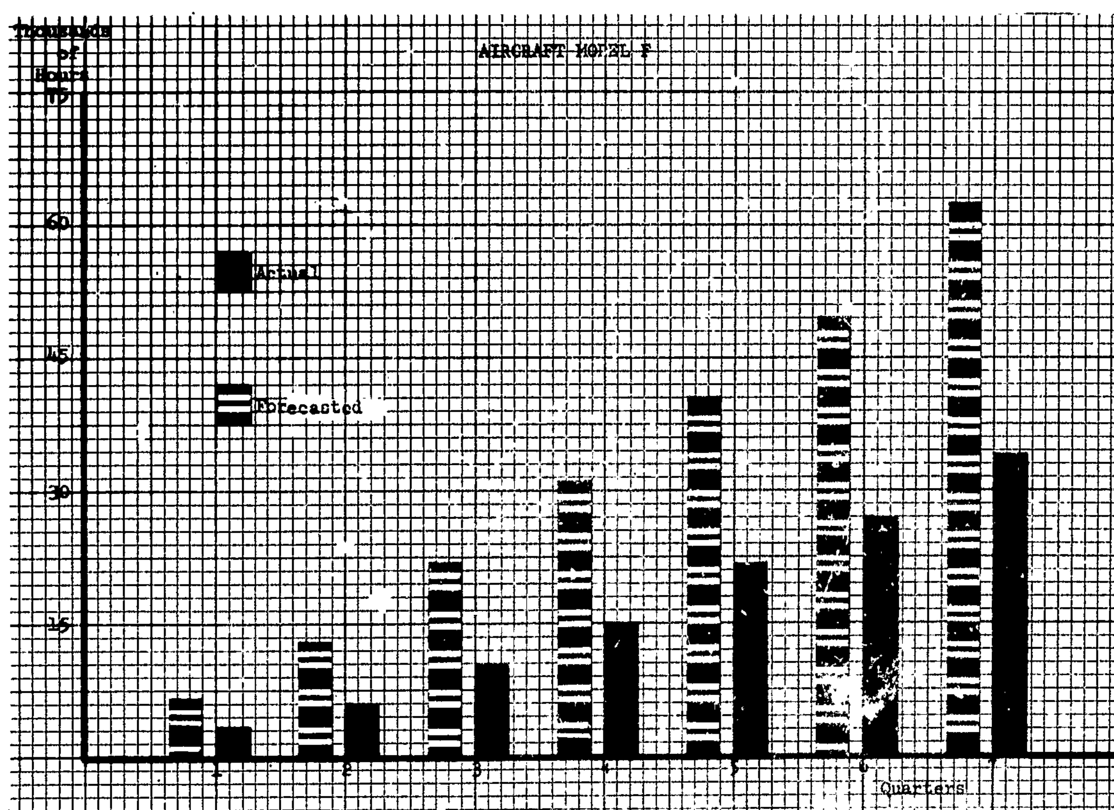


Figure 5.6

ACTUAL VERSUS FORECASTED FLYING HOURS
(Cumulative, World-Wide)

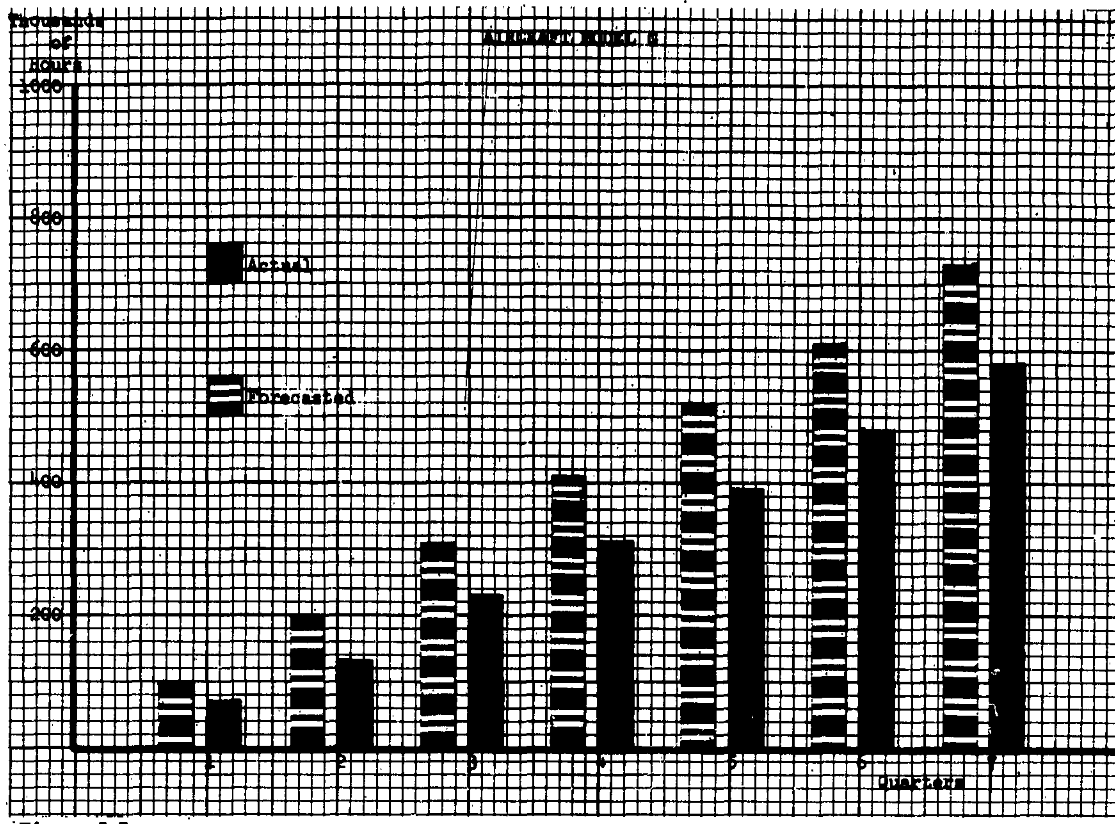


Figure 5.7

The practice of forecasting the flying hours for each customer area by factoring the total hours forecast by the percent of the total aircraft deployed in the area does not, however, stand up too well. Figure 5.8 shows the disparity between the distribution of aircraft and the distribution of flying hours over different areas. Data were tabulated from DA 1352 reports for six of the major geographical areas. As can be seen, an area with a relatively small number of aircraft frequently contributes an inordinately high fraction of the total hours flown. This indicates that Flying Hour Program forecasts should be made for individual customer areas and should be based not only on aircraft population but also on other program data such as the area's expected level of activity. Again, however, the relative stability of hours flown within an area from month to month (see the data tabulated in Tables III through VIII) indicates that a smoothed forecast of satisfactory precision could be made.

SHARE OF AIRCRAFT POPULATION COMPARED WITH
SHARE OF FLYING HOURS

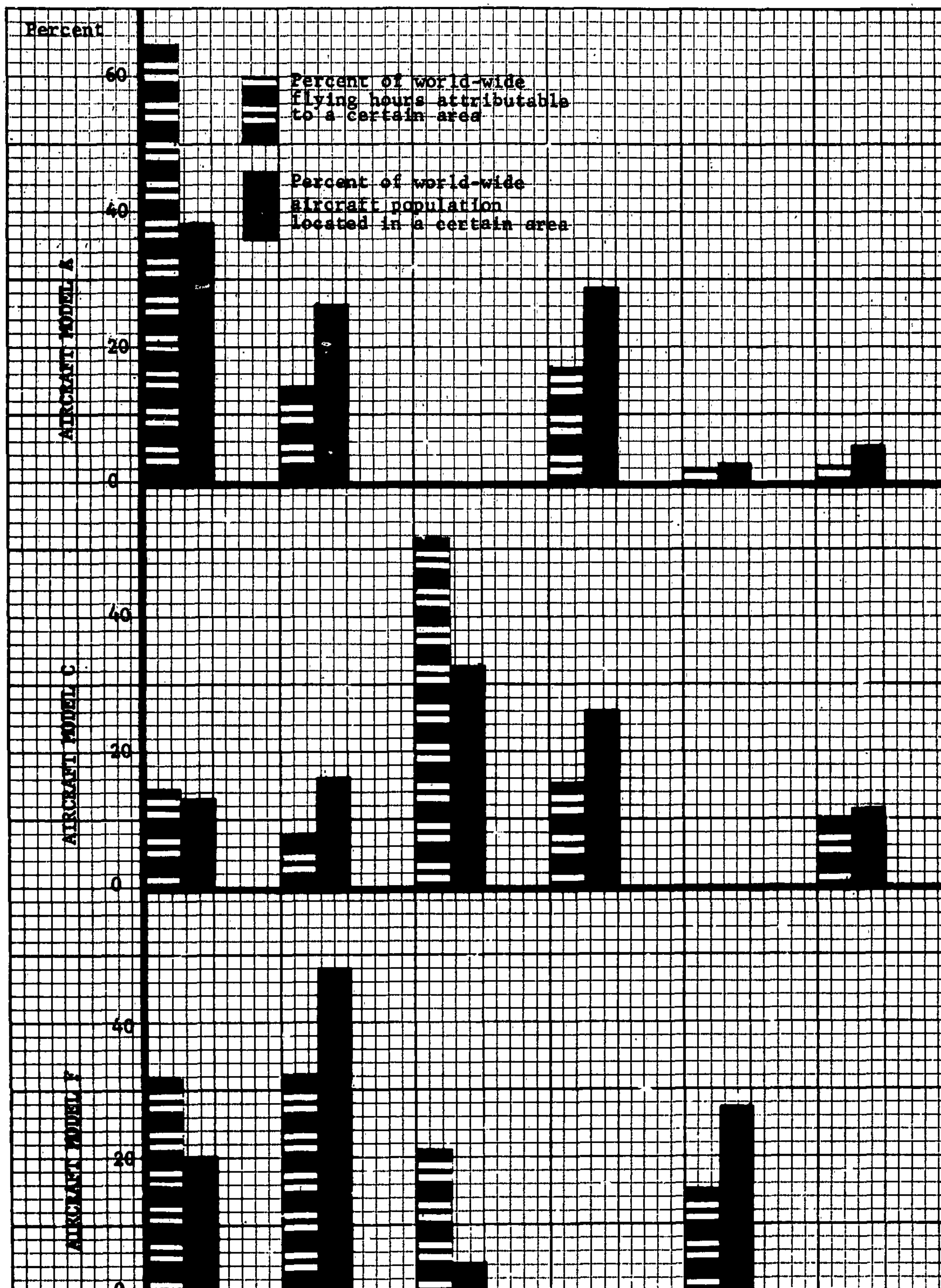


Figure 3.8

TABLE III

FLYING HOURS BY AREA, AIRCRAFT MODEL A
(Thousands of Hours)

MONTH	AREA I	II	III	IV	V	VI	TOTAL HRS/YR ALL AREAS
1	9.4	1.2	-	3.8	0.3	0.4	
2	13.0	2.8	-	4.3	0.3	0.5	
3	10.6	2.1	-	3.8	0.3	0.7	
4	12.6	4.1	-	3.9	0.4	0.5	
5	12.0	3.7	-	3.5	0.4	0.4	
6	12.0	2.4	-	3.2	0.2	0.3	
7	11.2	3.6	-	2.9	0.3	0.0	
8	10.6	2.3	-	2.4	0.3	0.6	
9	13.2	2.1	-	2.5	0.2	0.2	
10	10.3	1.5	-	2.1	0.3	0.6	
11	11.3	1.5	-	1.3	0.3	0.5	
12	7.5	1.6	-	1.2	0.3	0.3	
TOTAL	133.7	28.9	-	34.9	3.6	5.0	206.1
% Hrs	64.9	14.1	-	16.9	1.7	2.4	
% Aircraft	38.3	26.5	-	28.7	2.9	3.6	

TABLE IV

FLYING HOURS BY AREA, AIRCRAFT MODEL B
(Thousands of Hours)

MONTH	AREA I	II	III	IV	V	VI	TOTAL HRS/YR ALL AREAS
1	3.6	4.6	7.3	0.7	1.3	0.2	
2	4.1	4.5	5.2	0.5	1.6	0.2	
3	5.2	6.6	6.7	0.5	1.6	0.2	
4	3.7	7.0	4.8	0.6	1.5	0.3	
5	2.9	4.2	4.7	0.6	1.6	0.3	
6	2.3	4.1	4.0	0.5	1.3	0.2	
7	2.5	3.9	2.7	0.5	1.9	0.3	
8	2.0	3.2	1.9	0.4	1.3	0.2	
9	1.3	3.5	0.9	0.4	1.2	0.2	
10	0.9	3.1	0.7	0.5	1.1	0.5	
11	0.7	2.6	0.9	0.4	1.0	0.2	
12	0.4	2.8	0.9	0.4	1.0	0.2	
	29.6	50.1	40.7	6.0	16.4	3.0	145.8
% Hrs	20.3	34.4	27.9	4.1	11.2	2.1	
% Aircraft	16.1	40.2	27.0	3.5	11.3	1.9	

TABLE V

FLYING HOURS BY AREA, AIRCRAFT MODEL C
(Thousands of Hours)

MONTH	AREA I	II	III	IV	V	VI	TOTAL HRS/YR ALL AREAS
1	0.6	0.5	2.3	0.7		0.4	
2	0.8	0.6	2.3	0.7		0.4	
3	0.8	0.4	2.2	0.5		0.4	
4	0.7	0.3	2.9	0.9		0.6	
5	0.7	0.4	2.8	0.9		0.6	
6	0.8	0.4	2.6	1.0		0.6	
7	1.1	0.5	2.7	1.0		0.7	
8	1.2	0.5	3.1	0.9		0.5	
9	0.9	0.3	3.1	0.9		0.4	
10	1.1	0.3	2.7	0.9		1.1	
11	1.0	0.5	2.8	0.9		0.5	
12	0.7	0.4	4.2	0.9		0.6	
	9.4	5.1	33.7	10.2		6.8	65.2
% Hrs	14.4	7.8	51.7	15.6		10.5	
% Aircraft	13.1	16.3	33.0	26.2		11.4	

TABLE VI

FLYING HOURS BY AREA, AIRCRAFT MODEL D
(Thousands of Hours)

MONTH	AREA I	II	III	IV	V	VI	TOTAL HRS/YR ALL AREAS
1	2.1	3.0		0.1	3.6		
2	2.8	4.9		0.4	4.0		
3	2.4	4.1		0.3	4.1		
4	2.7	8.0		0.4	3.9		
5	2.2	5.3		0.4	4.5		
6	1.6	5.0		0.6	4.2		
7	2.9	4.9		1.2	4.9		
8	3.0	4.4		1.1	4.5		
9	2.6	3.9		1.4	4.7		
10	2.6	3.5		1.6	3.0		
11	2.3	3.3		1.8	2.6		
12	2.1	3.6		1.9	3.2		
	29.3	53.9		11.2	47.2		141.6
% Hrs	20.7	38.1		7.9	33.3		
% Aircraft	12.6	49.9		3.2	34.3		

TABLE VII

FLYING HOURS BY AREA, AIRCRAFT MODEL E
(Thousands of Hours)

MONTH	AREA I	II	III	IV	V	VI	TOTAL HRS/YR ALL AREAS
1	0.9	1.6	1.3				
2	1.0	2.0	1.9				
3	0.8	1.5	1.9				
4	1.0	1.8	1.7				
5	0.8	1.3	1.4				
6	0.6	1.1	0.9				
7	0.8	0.9	0.9				
8	1.0	0.8	1.0				
9	0.7	0.9	1.1				
10	0.6	0.8	1.0				
11	0.7	0.8	1.0				
12	0.4	0.5	1.3				
	9.3	14.0	15.4				38.7
% Hrs	24.0	36.2	39.8				
% Aircraft	15.8	49.5	34.7				

TABLE VIII

FLYING HOURS BY AREA, AIRCRAFT MODEL F
(Thousands of Hours)

MONTH	AREA I	II	III	IV	V	VI	TOTAL HRS/YR ALL AREAS
1	0.8	0.8	0.3		0.3		
2	1.0	1.2	0.4		0.5		
3	0.5	1.0	0.4		0.5		
4	0.8	1.3	0.5		0.4		
5	0.8	0.9	0.5		0.4		
6	0.7	0.6	0.6		0.4		
7	0.8	0.8	0.6		0.3		
8	0.8	0.6	0.6		0.4		
9	0.7	0.4	0.6		0.4		
10	0.8	0.6	0.5		0.2		
11	0.5	0.4	0.4		0.2		
12	0.5	0.4	0.4		0.1		
	8.7	9.0	5.8		4.1		27.6
% Hrs	31.5	32.6	21.0		14.9		
% Aircraft	20.2	47.9	4.2		27.7		

CHAPTER 6

DESCRIPTION OF THE PROPOSED MANAGEMENT AND CONTROL SYSTEM

This chapter provides a more detailed account of key elements in the proposed system. First the problems encountered in forecasting removals are analyzed and the conventional method based on historically observed issue rates is contrasted with the proposed forecasting model which is built on actuarial principles.

In the second section a world-wide inventory model is developed relating total systems inventory to customer service. This requires an exact classification of the elements in the supply and maintenance system and a definition of the customer service concept. It is shown how this model can be manipulated to yield a Desired Inventory Level and an "optimal" distribution pattern.

The Supply Control Study discussed in the third section is in effect the manipulation of the world-wide inventory model by the analyst. Input and output forms are discussed and a numerical example is given.

The fourth and last section deals with the Monthly Review, its uses, its relation to the Supply Control Study and its format.

6.1 FORECASTING REMOVAL RATES

A key factor to procurement, overhaul and distribution decisions is the number of component removals expected during some future time period, e.g., the next fiscal year. The least complicated method of estimating rates of this kind is projection of historical observations. Thus, if an estimate is required of the number of items to be shipped to Europe next year, the number of issues to Europe during the past year would be the starting point. Proportional adjustments may then be made to account for expected changes in gross factors such as flying hours, TBO, etc.

The historical method has the great virtue of being simple; no knowledge is required of what is actually happening to the reliability, age distribution of the population, repair and overhaul practices, etc. However, the accuracy of the historical method may be unsatisfactory if factors such as these exert a strong influence on removal rates. Considerable time was therefore spent during the course of this study in the analysis of field failure data obtained from the AVCOM Commodity Manager's Guide, from the Engine Reporting System, from TAERS and from the U.S. Air Force Actuarial Office in order to determine whether such factors influence removal rates. The results of these analyses are summarised in the following section.

6.1.1 ANALYSIS OF REMOVAL DATA

A convenient way of examining effects of various factors on component removal rates is by means of Survival Probability Curves. A Survival Probability Curve depicts the percentage of items in a group, all of which started operating at zero hours, that survive past a particular number of flying hours.* Curves of this type, constructed from the actual removal data, are used to illustrate the conditions that were found to exist, and to support the conclusions reached in this analysis.**

*A more complete description of Survival Probability Curves, their construction and their use in forecasting removals is given in Section 6.1.2.

**See Figures 6.3 through 6.19 which are included just preceding Section 6.1.4.

Percent of Items Surviving to TBO: Current Supply Control Procedures assume that a standard figure can be used to forecast the percent of items that will survive to their rated TBO without requiring overhaul. A figure of 80% has been used in supply control studies that were seen. However, performance of this kind was not observed at all in the data analyzed. The highest value of percent surviving to TBO observed was 65% (Figure 6.7). Values of as low as 1% were noted (Figures 6.11, 6.13). The wide range of values observed indicates that this factor will have to be determined for each item and that, as will be seen later, it must be expected that this value will change over time.

Survival Probabilities Related to Component Age: Some opinions have been voiced to the effect that failures are independent of the hours logged on the component and that an exponential failure model could, therefore, be employed in forecasting removals. However, all data reviewed indicated the opposite to be true. Only one of the items (Figure 6.10) shows a tendency in that direction but even that is suspect because the observations plotted covered an early period of the T63L1A Engine's life in the system. All other plots show a significant wear factor and that failure rates are age-dependent.

Existence of a Common Underlying Failure Model: Many attempts were made to find a probability distribution that, with proper choice of parameters, can be used to describe the survival probabilities of all items. The data analyzed in this study indicate that no single probability distribution can be used for this purpose. Many items (Figures 6.3, 6.4) exhibited a survival probability curve of the rectangular type. Others (Figures 6.5, 6.6, 6.7) showed relatively high survival probabilities during the early portion of the TBO cycle with a more rapid drop-off in the survival probabilities as the TBO is approached. One (Figure 6.8) exhibited this pattern but with a diminution of this drop-off in survival probability immediately before TBO. Some have expressed the view that survival probabilities ought to drop off sharply in the early ages of the TBO cycle, then stabilize until the later ages, giving the so-called "bathtub" curve if failure rates, rather than survival probabilities, are plotted. A few items (Figure 6.9) were found where these characteristics were shown to some degree but this was far from a general observation.

All these observations* led to the conclusion that it would be impossible to fit a single probability distribution to all items over all time.

*It is of interest to note that similar observations were made on U.S. Air Force data (see Figures 6.15, 6.16, 6.17).

A decision was, therefore, reached that an age-dependent forecasting method that is distribution-free would have to be used.

Effects of Product Improvement on Survival Probability: It has been asserted that Survival Probabilities ought to improve as product improvements are incorporated into the items, i.e., that we should expect failure rates to be high when an item is newly introduced into the system but that these failure rates ought to improve as the item undergoes engineering improvements. This was found to be true as is graphically illustrated in Figures 6.10 and 6.18. Figure 6.10 covers observations made in the period 1 January 1961 through 30 September 1961. Figure 6.18 (refer to overhaul removals only) covers the period of about June 1962 to about November 1963. As can be seen the improvement in survival probabilities is quite dramatic. This indicates that the forecasting procedure, if it is to be effective, must take into account the fact that failure rates will tend to change over time and that procurement decisions, particularly, must take this change into account.

TBO Changes Over Time: Nearly all items studied had undergone a number of TBO changes over the course of time covered by the data. These changes were indicated on some of the plots (see Figures 6.11, 6.12, 6.19). This points up one of the difficulties of using a single-value (such as Mean-Time-Between-Overhauls) prediction of removal rates based upon observations of historical data. The forecasting procedure must, if it is to be effective, incorporate a method of treating expected extension of the TBO. This, again, is an important factor in forecasting the level of overhaul and repair activity to be supported and in determining the number of spares the system ought to carry after product improvement goals have been achieved.

Differences in Survival Probabilities Between Customer Areas: It seems intuitively true that differences in climatic conditions, type of use, level of maintenance skills, etc., ought to have a bearing on survival probabilities and that items in certain areas ought to exhibit better performance than in others. Unfortunately, the amount of data available to test this assumption was very limited. However, this condition was noted on one item (Figure 6.13) where survival probabilities at given flying hours were much less in Viet Nam than in other theatres. It was concluded, therefore, that it would be better to select a forecasting procedure that would permit taking such differences into account. It is believed that, in time, sufficient data will become available to enable satisfactory forecasts of these differences to be made.

The conditions that were found to exist in this analysis pointed up the fact that the forecasting method recommended for use with the proposed management and control system would have to take into account the factors of age-dependency of failures, changing failure rates, changing TBO's, and that no single probability distribution is adequate to describe all modes of failure observed. The Actuarial Method, which is described in the following section, is felt to be most suitable for use under these conditions.

6.1.2 THE ACTUARIAL METHOD

The actuarial method of forecasting was originally developed by insurance actuaries for the U.S. Air Force and has been applied to the forecasting of removal rates for aircraft engines on a routine basis since 1958 with very good results. The method has been proved to be particularly effective in those cases where the chance of removal of a component depend upon its "age".

This is certainly true for the aircraft components considered in this study, not only because the TBO triggers mandatory removal when a certain number of flying hours has been logged, but also because the chances of a premature failure increase with the number of flying hours.

The proposed system closely parallels the procedures for determining actuarial failure rates, life expectancy and forecasting future failures for selected high-cost aeronautical items and aircraft engines used by the USAF.*

The first step is to compute actuarial failure rates, analogous to a mortality table: the failure rate represents the chance that an item fails when it is exposed to flying through a certain "age" interval. For instance, the failure rate for the interval between 50 and 100 flying hours signifies the chance that an item, still alive at 50 hours, will fail before it reaches 100 hours. The data required for estimating these failure rates are exposures and failures, or more specifically:

*U.S. Air Force T.O. 00-25-217 and T.O. 00-25-128

Interval	0-100	100-200	200-300
Failure Rate	10%	20%	33.3%
% Failing	10%	18%	24%
% Surviving	90%	72%	48%

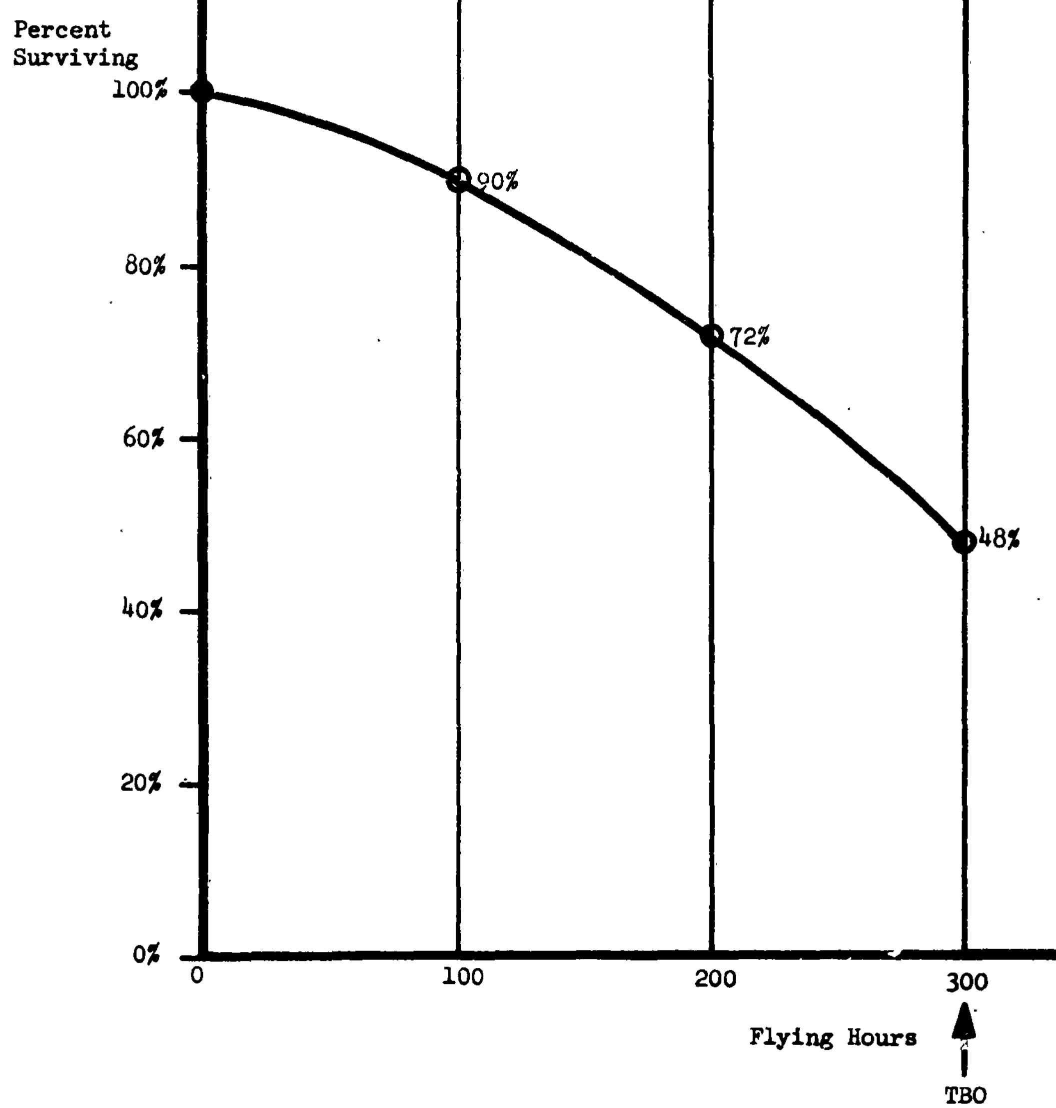


Figure 6.1

(a) the age of items at the beginning of the observation period, or at the time of installation if installed during the period, and

(b) the age of items at the time of removal or at the end of the observation period if not removed during the period.

The failure rate in a certain flying hour interval is equal to the number of failures recorded in that interval divided by the number of times an item was "exposed" to the interval.

Knowing the failure rates for a particular item, a simple calculation then yields the number of items that survive past a given age, starting with one hundred items at zero hours and operating each one of them until failure. This is the <u>Survival Probability Curve</u> of the item, which presents a meaningful picture of the item's reliability. Figure 6.1 illustrates the relationship between actuarial failure rates and survival probabilities with an example:

> The failure rate for the interval 0-100 hours is 10% which means that of the 100 items starting out at 0 hours, 90 will on the average survive to 100 hours; the failure rate for the interval 100-200 hours is 20% which means that of these 90 items 20%, or 18 items, are expected to fail, resulting in an average of 72 items surviving to 200 hours. Of these 72 items, an average of 33.3% or 24 items fails in the interval 200-300 hours leaving 48 items to reach the TBO of 300 hours without premature failure.

Application of this actuarial analysis to historical data has many benefits. It gives a true picture of component reliability by not only considering those items which failed but also those which did not fail in the observation period. Especially during the early stages of the life cycle of a weapon system, information about the items that have survived is often more important than information about those that have failed. The correctly computed survival probabilities or failure rates provide a better estimate of the mean-time-between-overhauls than can be obtained in conventional ways; namely, the mean-time-between-overhauls is equal to the area under the survival probability curve. Another important result is that under stable conditions, the age distribution of items in the system eventually takes on the same shape as the survival probability curve.

The simplest forecast deserving the "actuarial" label is probably to divide the total flying hour program by the actuarial mean-time-between-overhauls. This is fine for items which have been in the system for a long time, where the (flying hour) age distribution of the population has reached a stable pattern. However, in the early stages, age distributions are very unstable and this simple actuarial forecast, which does not take into account changes in age distributions, produces a sizable error.

Instead, the recommended forecasting procedure uses the current ages to group the installed items by age intervals. These age classes are then operated on paper, as it were, applying the actuarial failure rates and counting the removals until the number of flying hours projected for the period to be forecast has been completed. In other words, the expected number of removals is found by starting with the number of items in a certain age interval and computing the number that will fail as they age into the next interval; the ones that failed are replaced by zero hour items so they now enter the interval that starts with zero hours; the ones that survived enter the next interval. The process is repeated until we have "flown" a number of intervals corresponding to the average number of flying hours per aircraft.

6.1.3 A NUMERICAL EXAMPLE

The following hypothetical example will clarify the different elements of the actuarial forecasting process. Table IX shows, for a group of 30 aircraft, what happened during FY 1964. The first aircraft, for instance, started out FY 64 with an engine which had already logged 150 hours on it. This engine failed prematurely at 290 hours and was replaced with a zero hour engine (the assumption of replacement by a zero hour engine is made all through this example; in other words, removal always results in overhaul). The same data is shown again in Table X but by item. In Table XI are tabulated the number of exposures and failures from Table X resulting in the failure rates and survival probabilities. An exposure is the equivalent of an item operating through the entire exposure interval; fractional exposures appear when an item flies through only a portion of an interval, except that in case of a failure removal during an interval we count a full exposure as if the item reached the end of the interval. For example: item #1 contributes one exposure in the interval 150-200 hours, one exposure in 200-250 hours and one exposure in 250-300 hours; item #2 contributes one exposure to each of the intervals 0-50, 50-100, and 100-150 plus .4 of an exposure in the interval 150-200; item #3 contributes .2 of an exposure in 200-250 hours and a full exposure in all intervals between 250 and 500 hours.

Figure 6.2 shows a plot of the "crude" survival probabilities in Table XI and how a line could be fitted through the points thus obtained. This smooth line is next translated into smoothed failure rates and survival probabilities as shown in Table XII.

Now the stage is set for the actual forecast: how many removals are expected during FY 65 under program calling for an average of 300 flying hours per plane. In Table XIII, the items installed at the start of FY 65 (see Table IX) are first grouped into age intervals, and then operated on through six 50 hour cycles (6x50=300). It is shown that the number of removals expected in the first cycle is equal to 2.54, in the second 1.66, etc. for a total forecast of 18.22 removals.

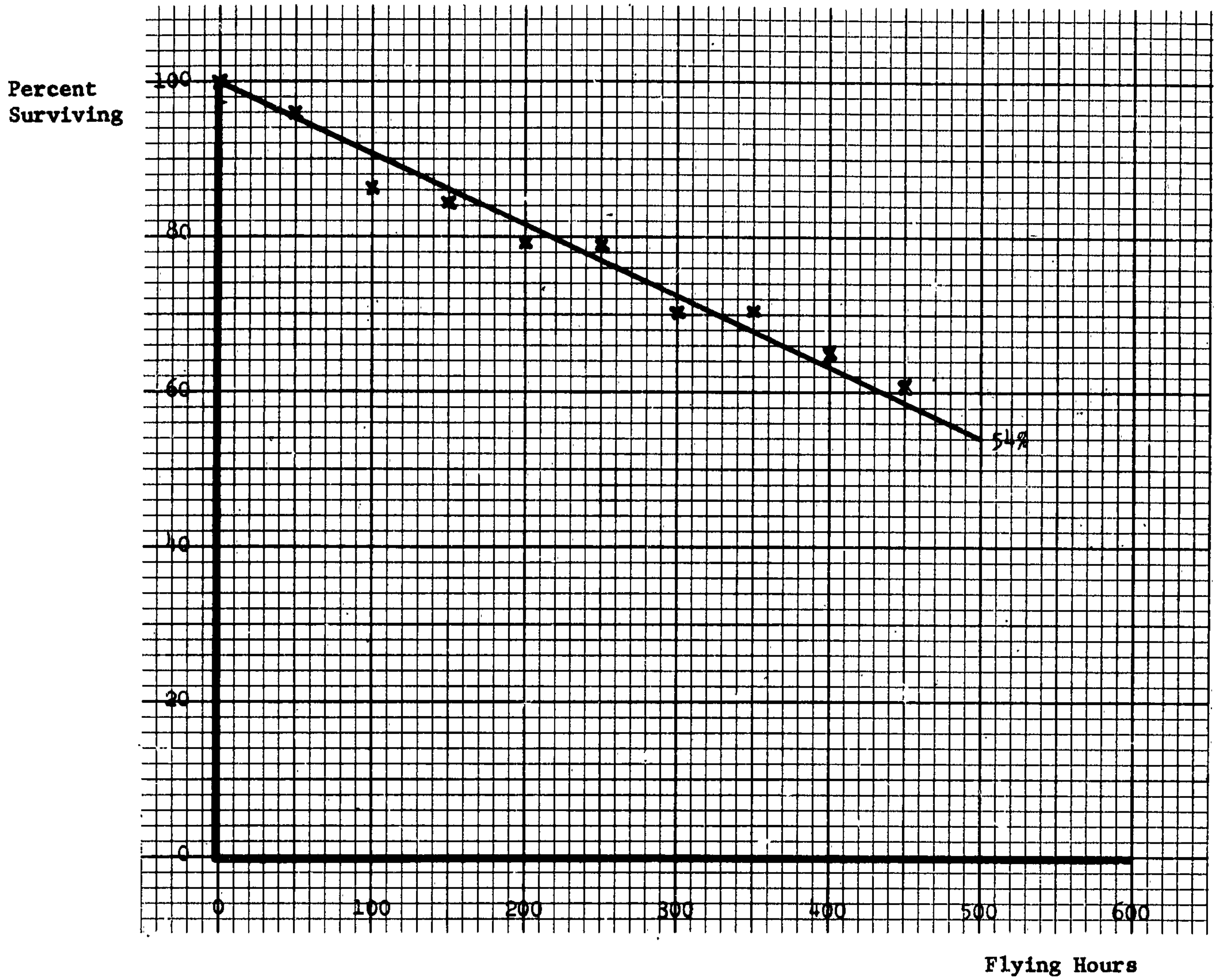

Percent
Surviving
100
80
60
40
20
0
0
100
200
300
400
500
600
54%
Flying Hours

Figure 6.2

TABLE IX

Aircraft No.	Age of Installed Item, Start of FY 64	Failures + TBO (=500 hrs) removals during FY 64	Age of Installed Item End of FY 64
1	150	290	170
2	240	500, 30	300
3	40	70,500	60
4	100	500	110
5	50	-	200
6	0	-	460
7	310	500	40
8	140	500	180
9	60	500	110
10	70	-	280
11	230	500	90
12	70	-	130
13	440	500	310
14	20	-	150
15	420	500,150	50
16	40	270	240
17	380	500, 50	230
18	130	370	10
19	60	500	0
20	490	500	230
21	30	-	300
22	480	500, 50	320
23	60	500	80
24	430	500,110	500
25	400	500	90
26	190	430	190
27	260	-	300
28	40	-	130
29	60	-	110
30	130	-	140

TABLE X

Item No.	Aircraft No.	Enters Observation Period with:	Leaves Observation Period with:	Reason*
1	1	150	290	PF
2	1	0	170	
3	2	240	500	
4	2	0	30	PF
5	2	0	300	
6	3	40	70	PF
7	3	0	500	
8	3	0	60	
9	4	100	500	
10	4	0	110	
11	5	50	200	
12	6	0	460	
13	7	310	500	
14	7	0	40	
15	8	140	500	
16	8	0	180	
17	9	60	500	
18	9	0	110	
.	.	.	.	
.	.	.	.	
.	.	.	.	

*PF = premature failure

= other, including TBO removals, survival until end of period without failure

TABLE XI

Flying Hour Interval	Full Exposures A	Fractional Exposures B	Total Exposures C=A+B	Failures D	Crude Failure Rate E=D/C	% Surviving Start of Interval F	% Failing G
0-50	24	.2 .8 .6 .2 .2 .4 .2	26.6	1	3.76	100.00	3.76
50-100	22	.2 .8 .6 .8 .6 .8 .8 .6 .8 .8	28.8	3	10.42	96.24	10.03
100-150	23	.2 .2 .2 .6 .4 .6 .2 .2	25.6	1	3.91	86.21	3.37
150-200	20	.4 .6 .2 .8	22.0	1	4.55	84.84	3.77
200-250	17	.2 .4 .8 .6 .6	19.6	-	-	79.07	-
250-300	18	.6 .8	19.4	2	10.31	79.07	8.15
300-350	11	.8 .2 .4	12.4	-	-	70.92	-
350-400	12	.6	12.6	1	7.94	70.92	5.63
400-450	13	.2 .2 .6 .4	14.4	1	6.94	65.29	4.53
450-500	14	.2 .4	14.6	-	-	60.76	-

TABLE XII

SMOOTHED FAILURE RATES

Interval	Smoothed Failure Rate	Smoothed % Surviving at Start of Interval	Smoothed % Failing
0-50	4.60	100.0	4.6
50-100	4.82	95.4	4.6
100-150	5.06	90.8	4.6
150-200	5.33	86.2	4.6
200-250	5.64	81.6	4.6
250-300	5.97	77.0	4.6
300-350	6.35	72.4	4.6
350-400	6.79	67.8	4.6
400-450	7.28	63.2	4.6
450-500	7.86	58.6	4.6

TABLE XIII

Interval	Starting Age Distribution	Removals in First Cycle	Age Distrib. after First Cycle	Removals in 2nd Cycle	Age Distrib. after 2nd Cycle	etc.
0-50	4	.184	2.54	.1168	1.66	
50-100	4	.1928	3.816	.1839	2.4232	
100-150	7	.3542	3.8072	.1926	3.6321	
150-200	4	.2132	6.6458	.3542	etc.	
200-250	3	.1692	3.7868	.2136		
250-300	5	.2985	2.8308	.1690		
300-350	2	.1270	4.7015	.2985		
350-400	-	-	1.8730	.1272		
400-450	-	-	-	-		
450-500	1	1.0	-	-		
	TOTAL =	2.54		TOTAL=1.66		

TOTAL FAILURES:	1st cycle	2.54
	2nd cycle	1.66
	3rd cycle	1.73
	4th cycle	3.30
	5th cycle	5.34
	6th cycle	3.77
	TOTAL	18.22

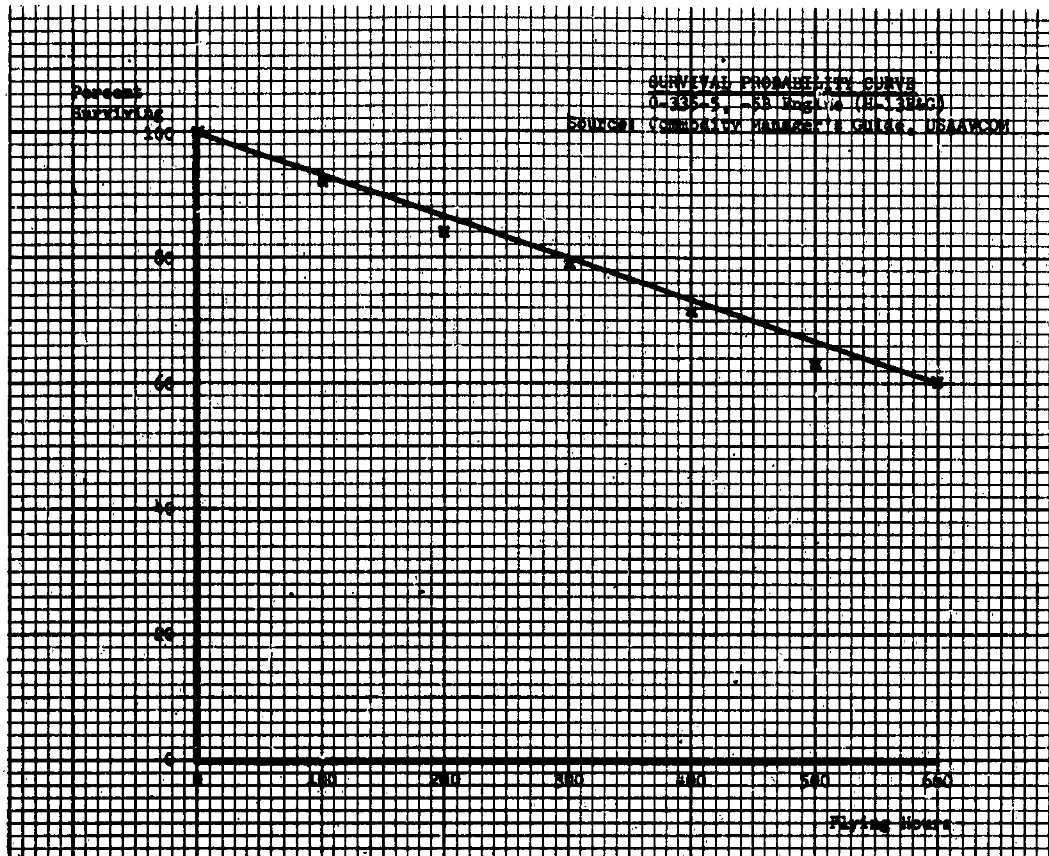


Figure 6.3

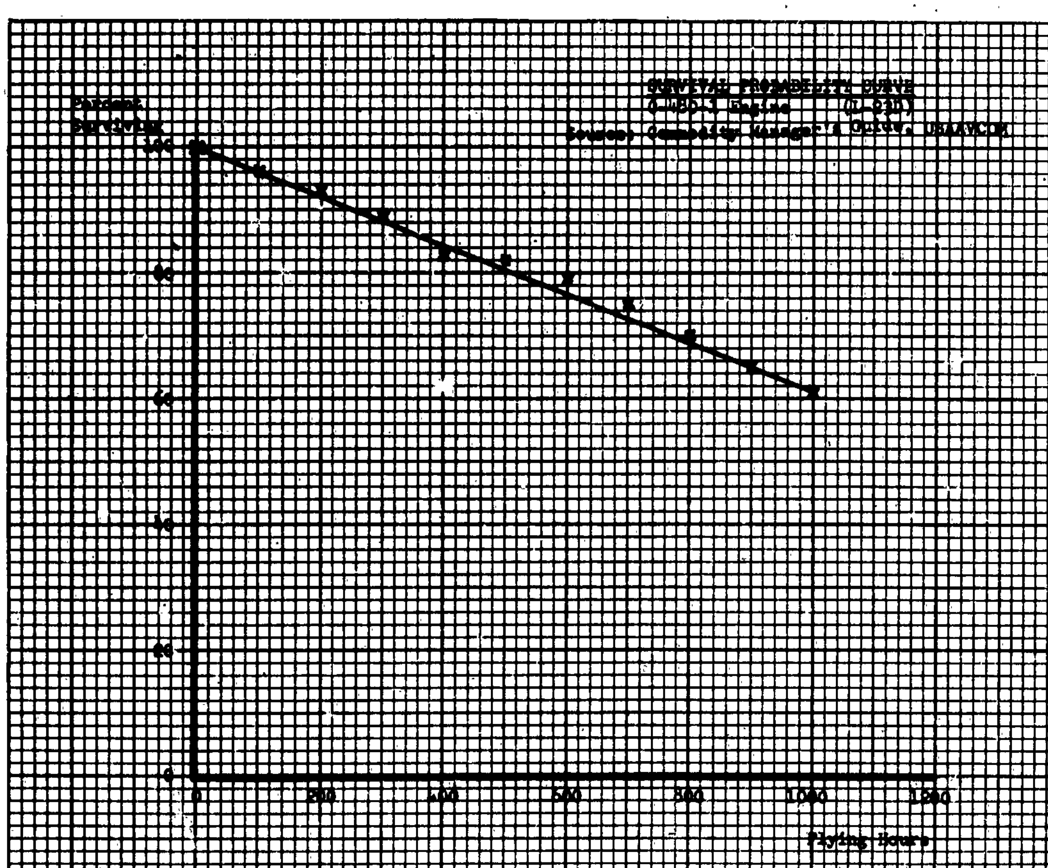


Figure 6.4

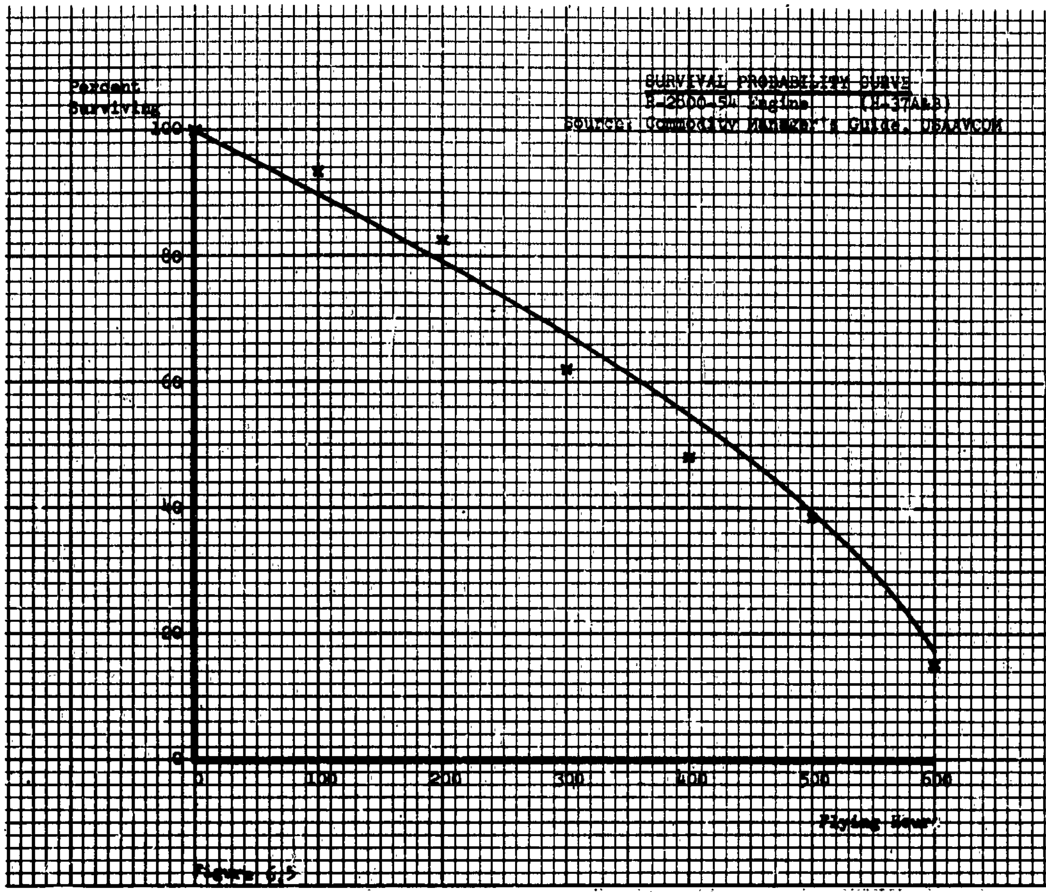


Figure 6.5

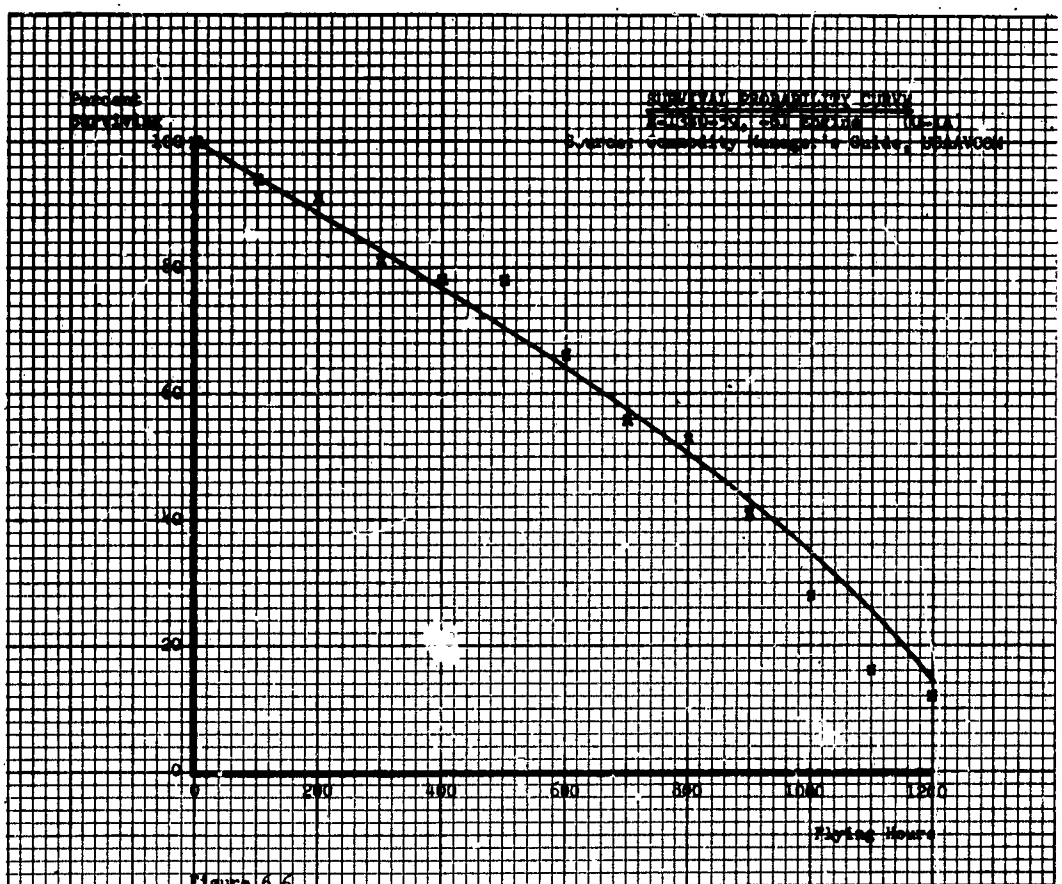


Figure 6.6

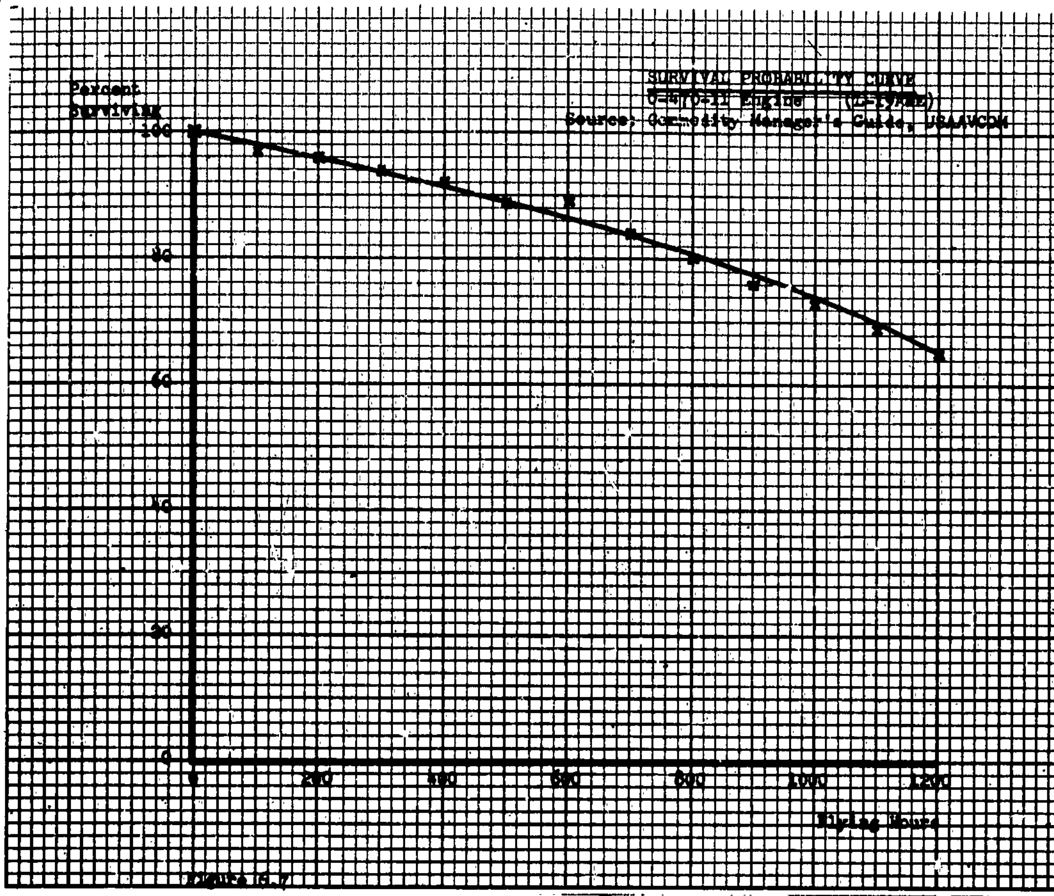


Figure 6.7

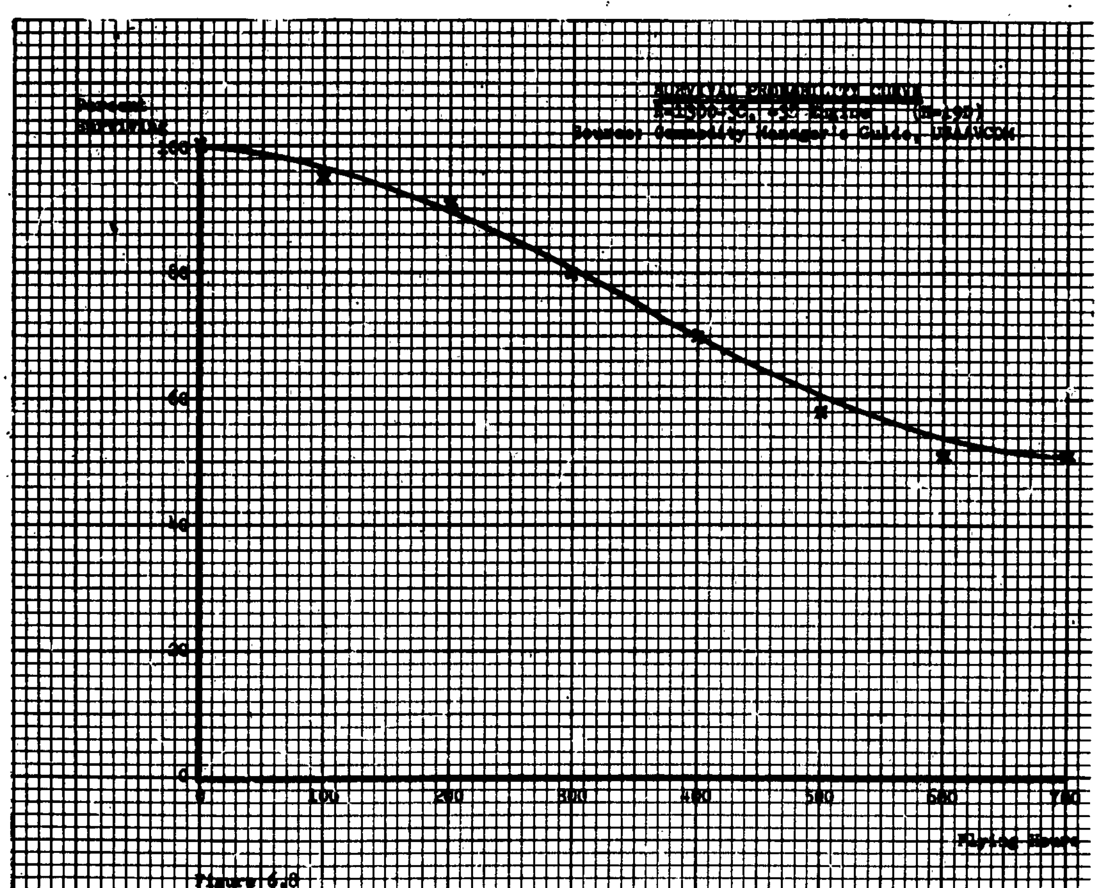


Figure 6.8

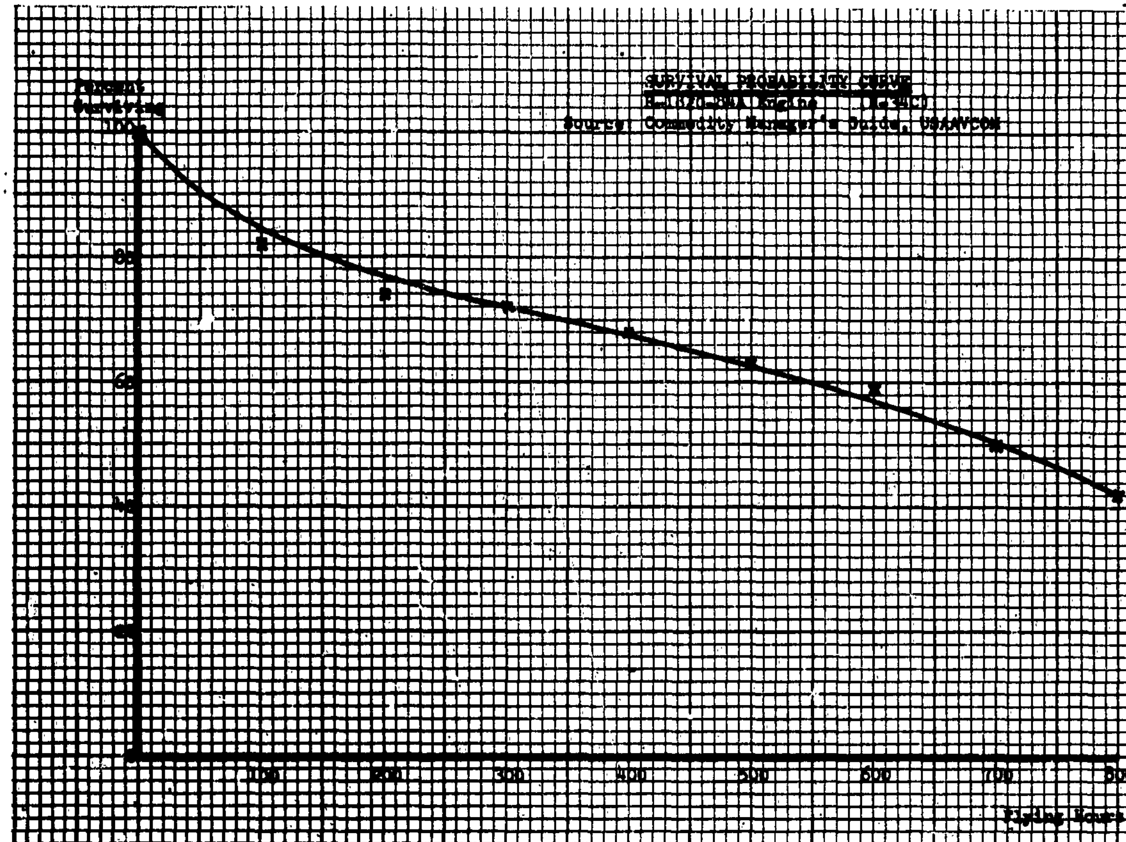


Figure 6.9

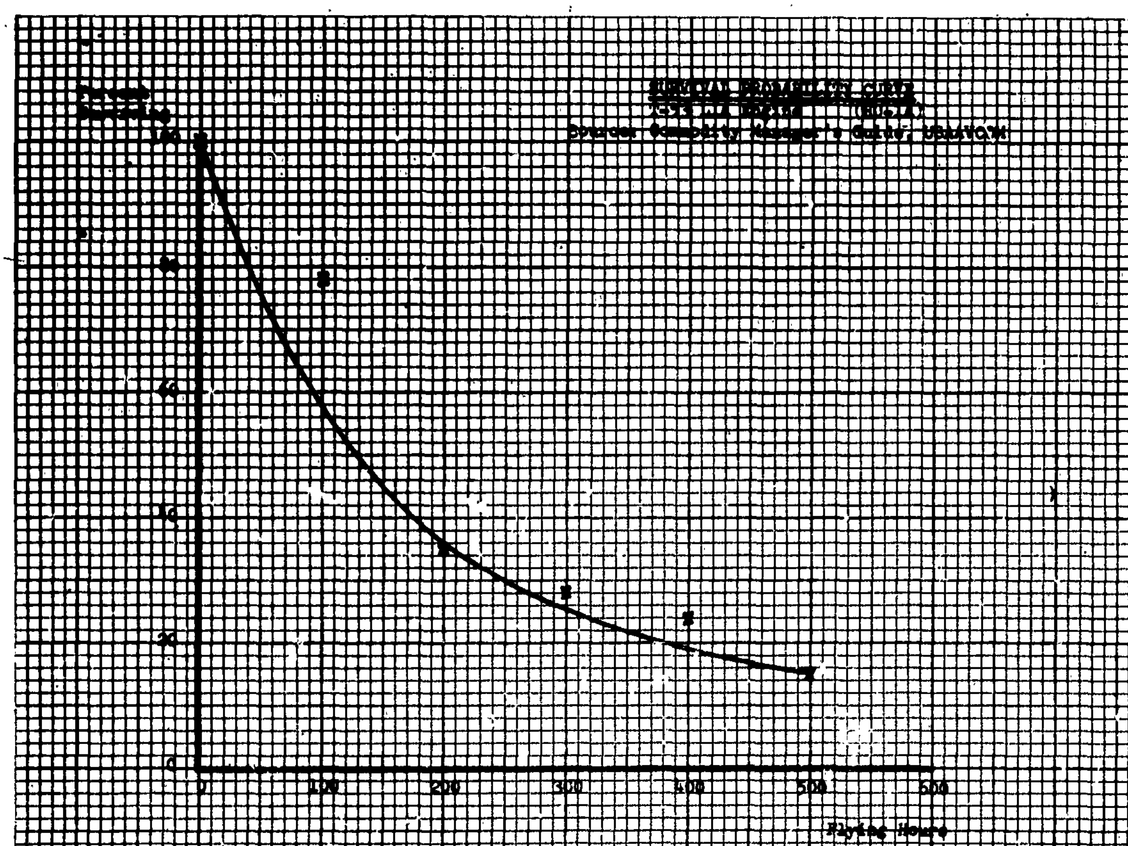


Figure 6.10

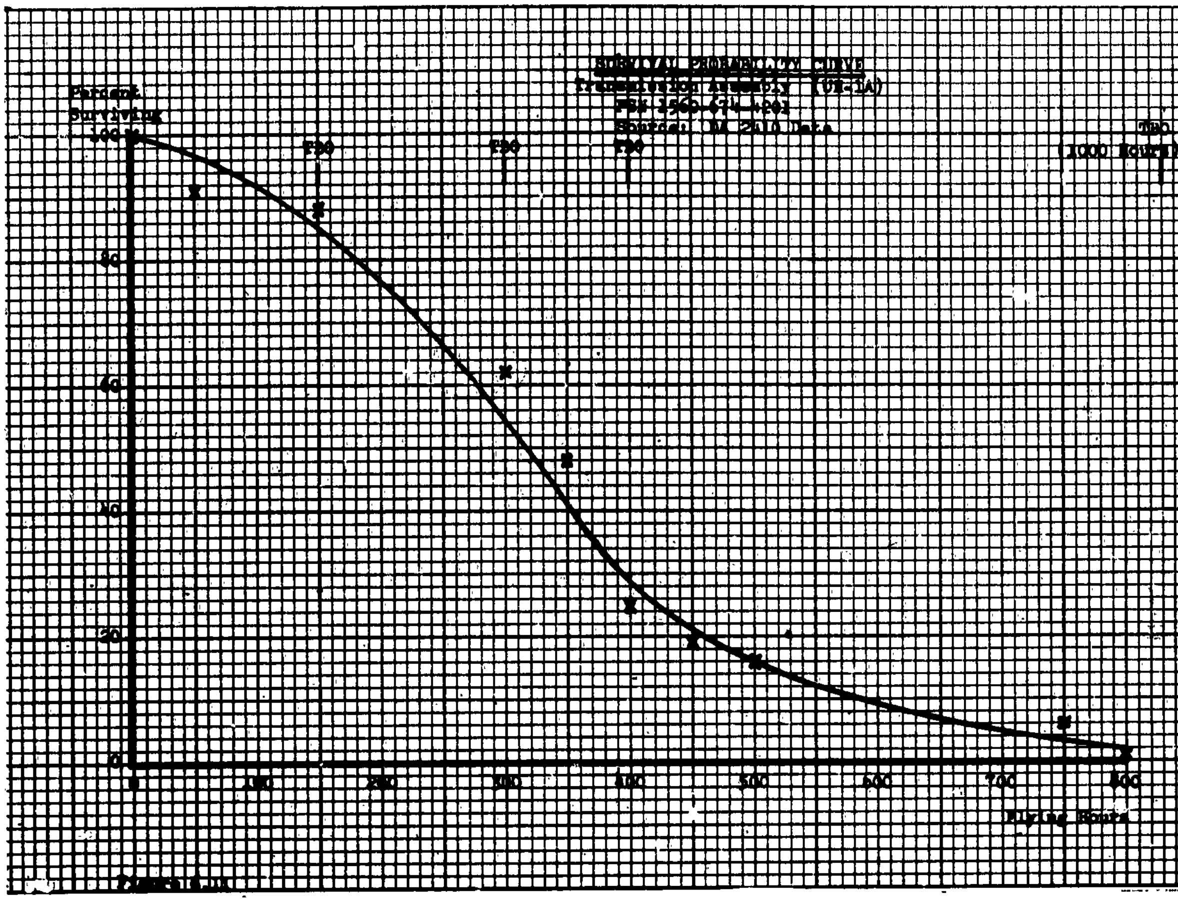


Figure 6.11

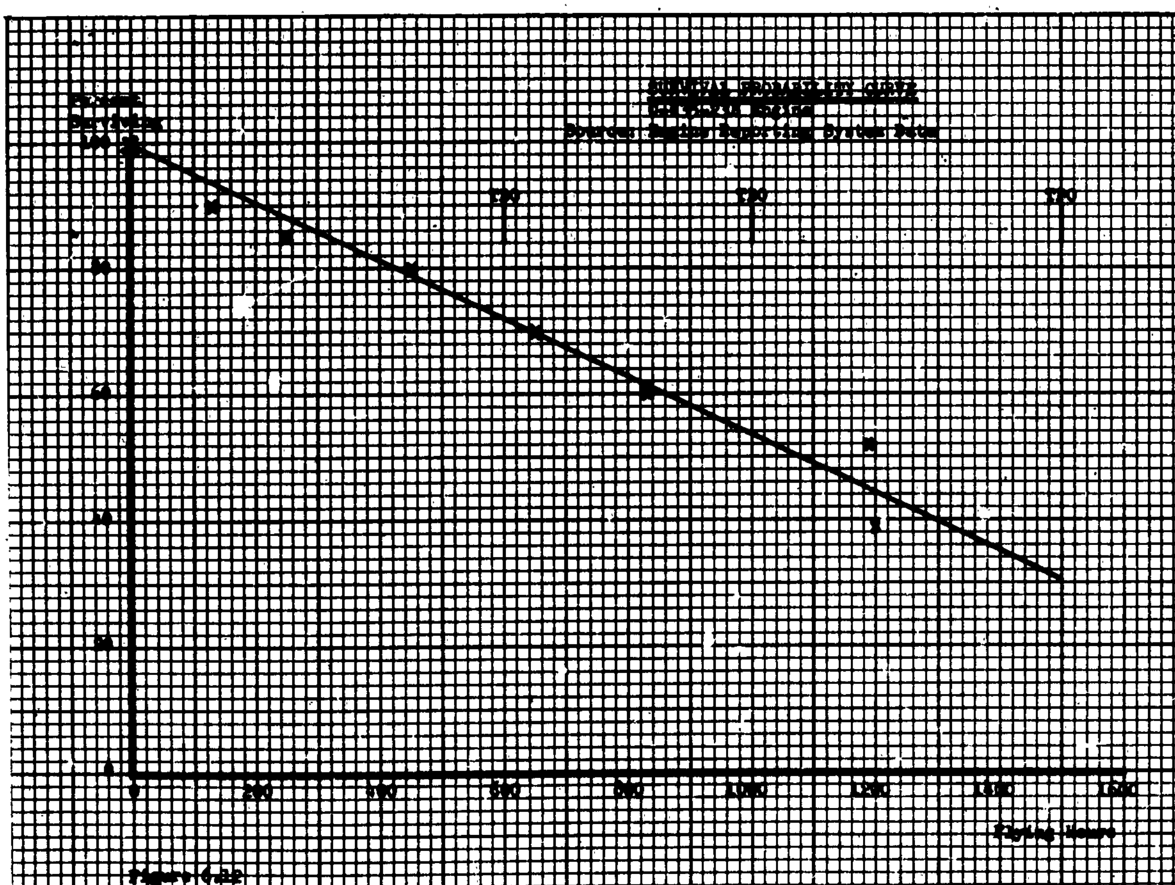


Figure 6.12

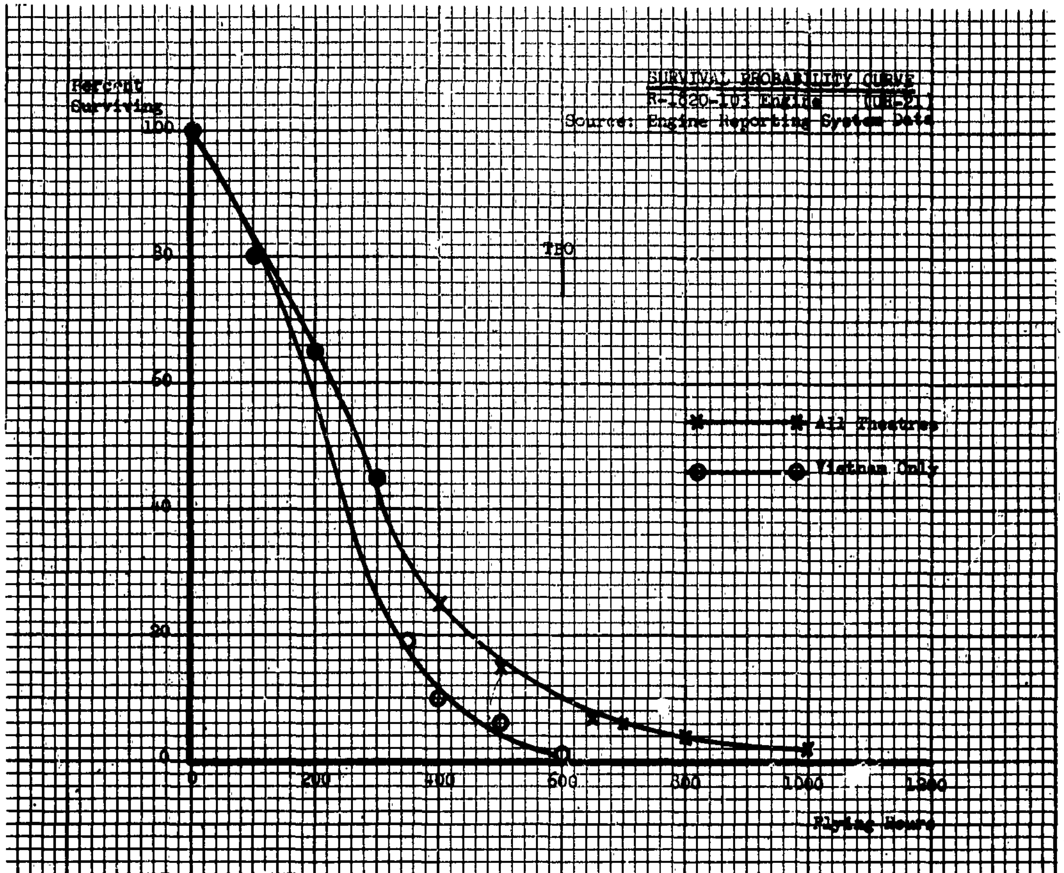


Figure 6.13

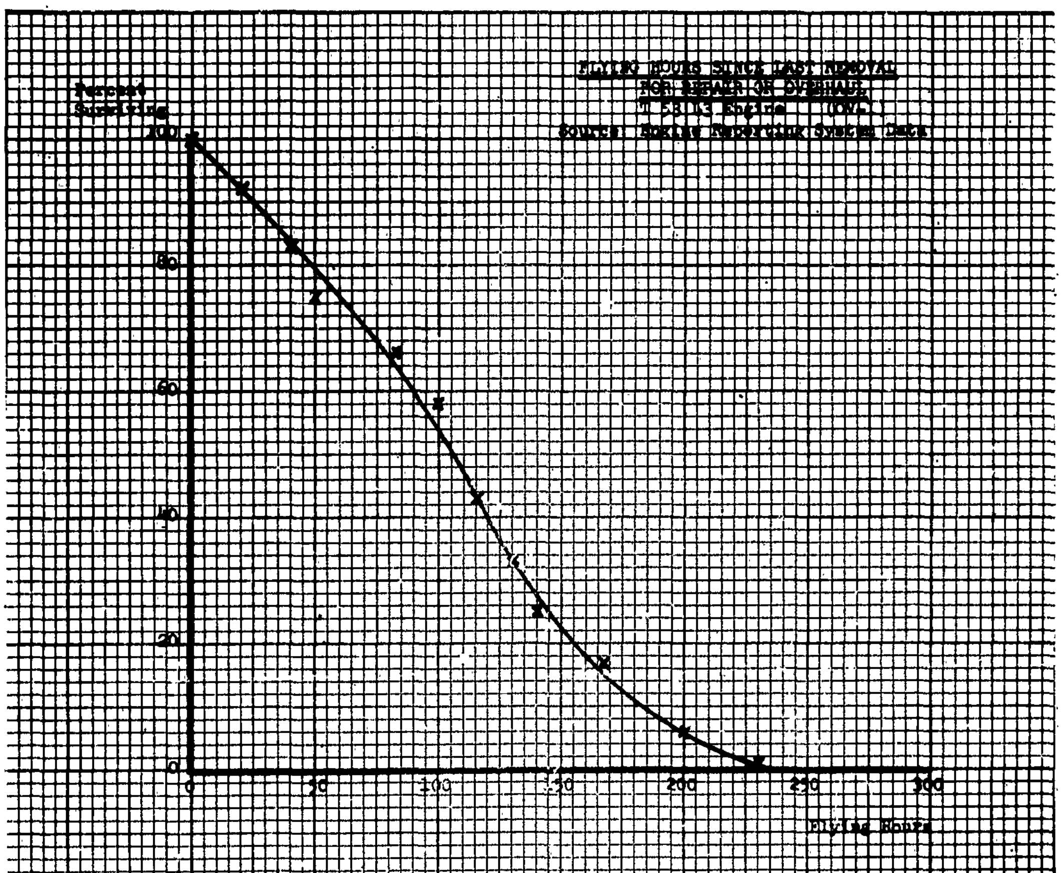


Figure 6.14

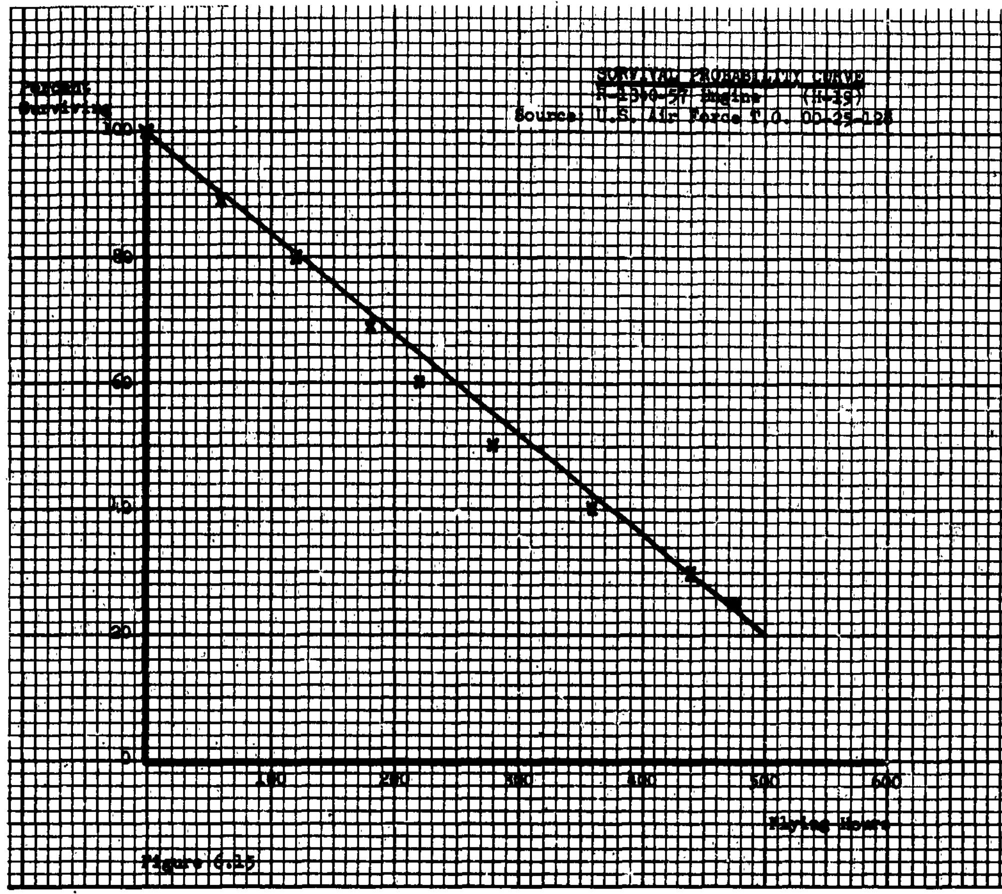


Figure 6.15

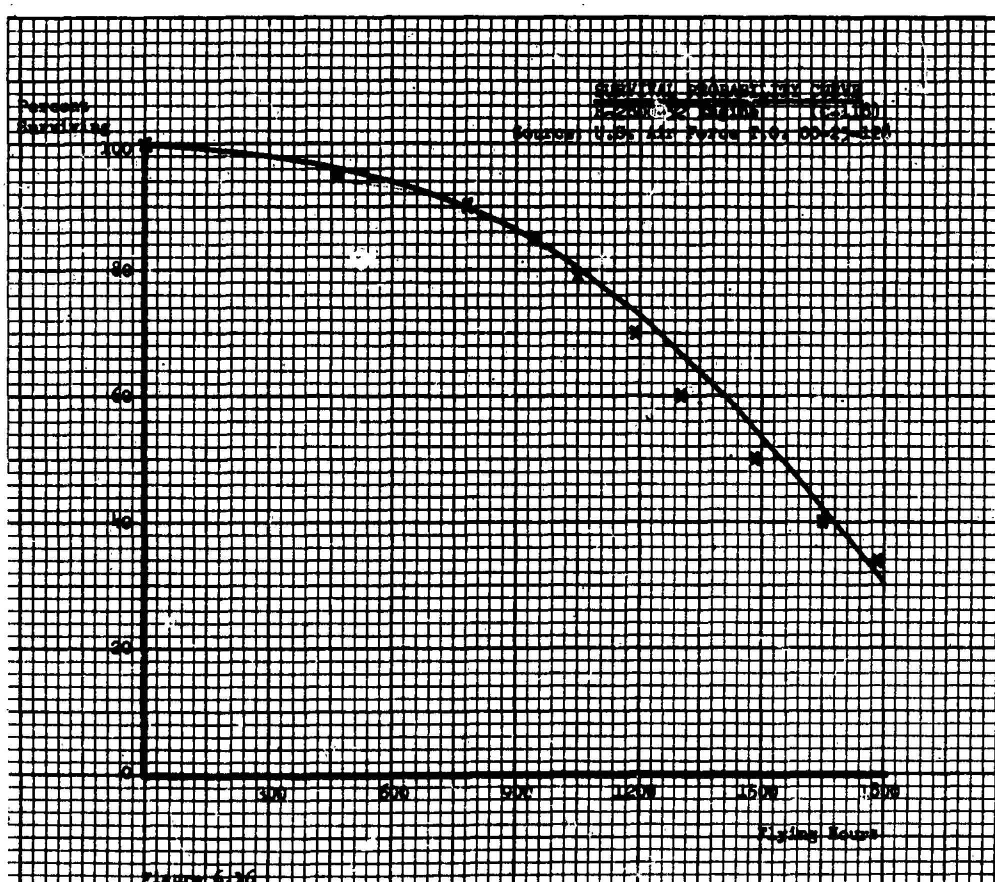


Figure 6.16

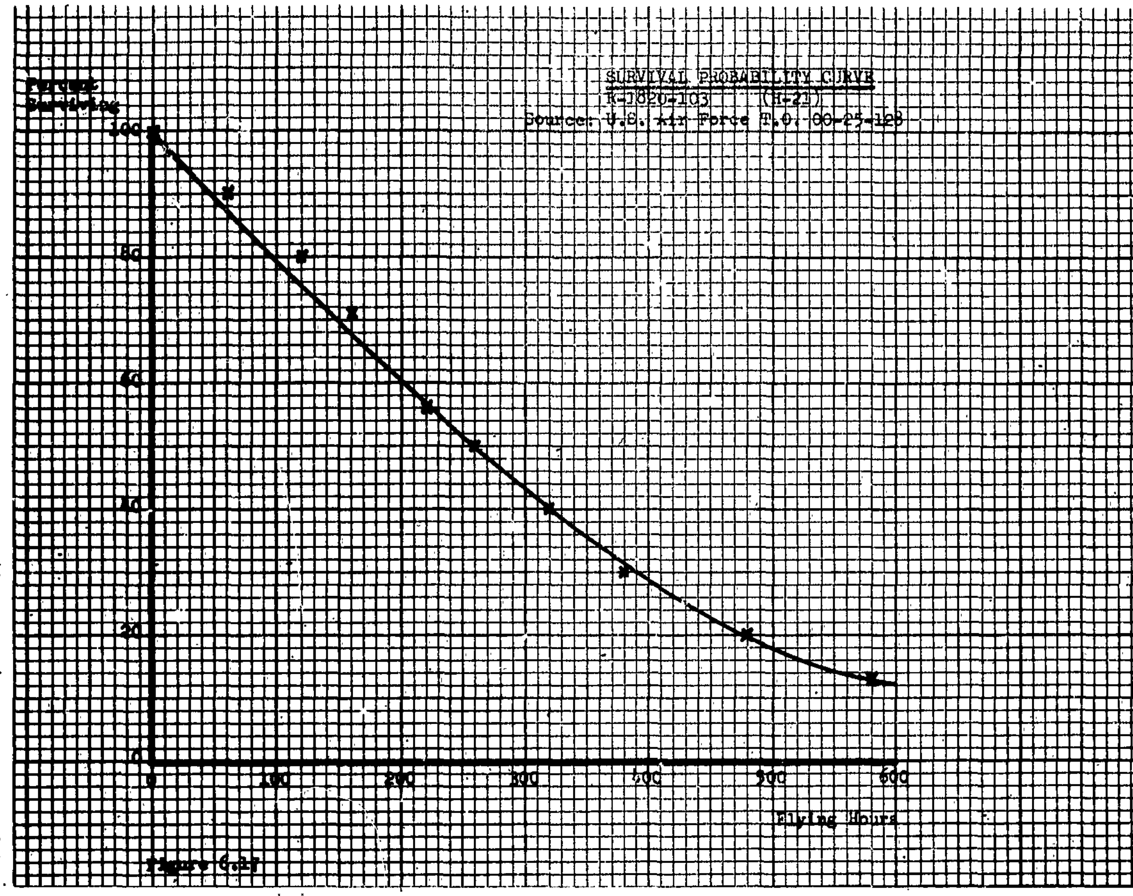


Figure 6.17

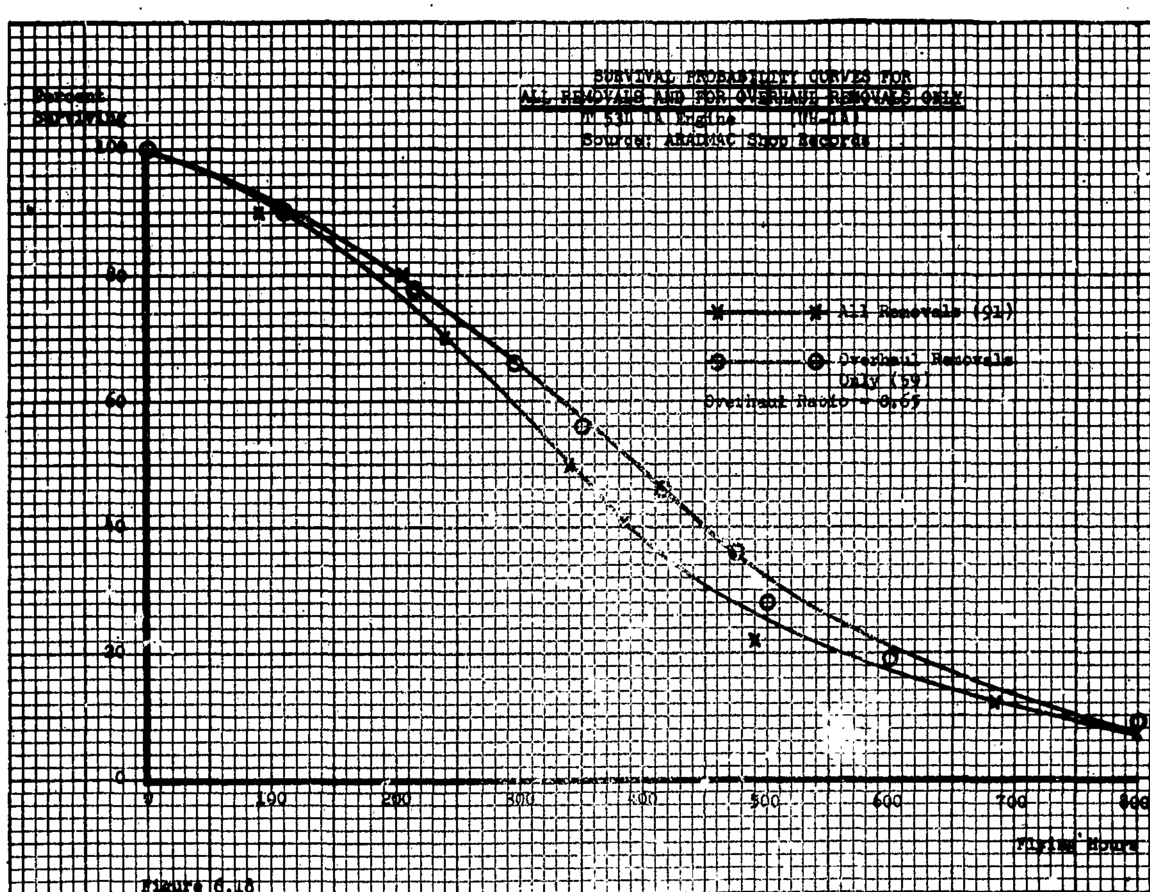


Figure 6.18

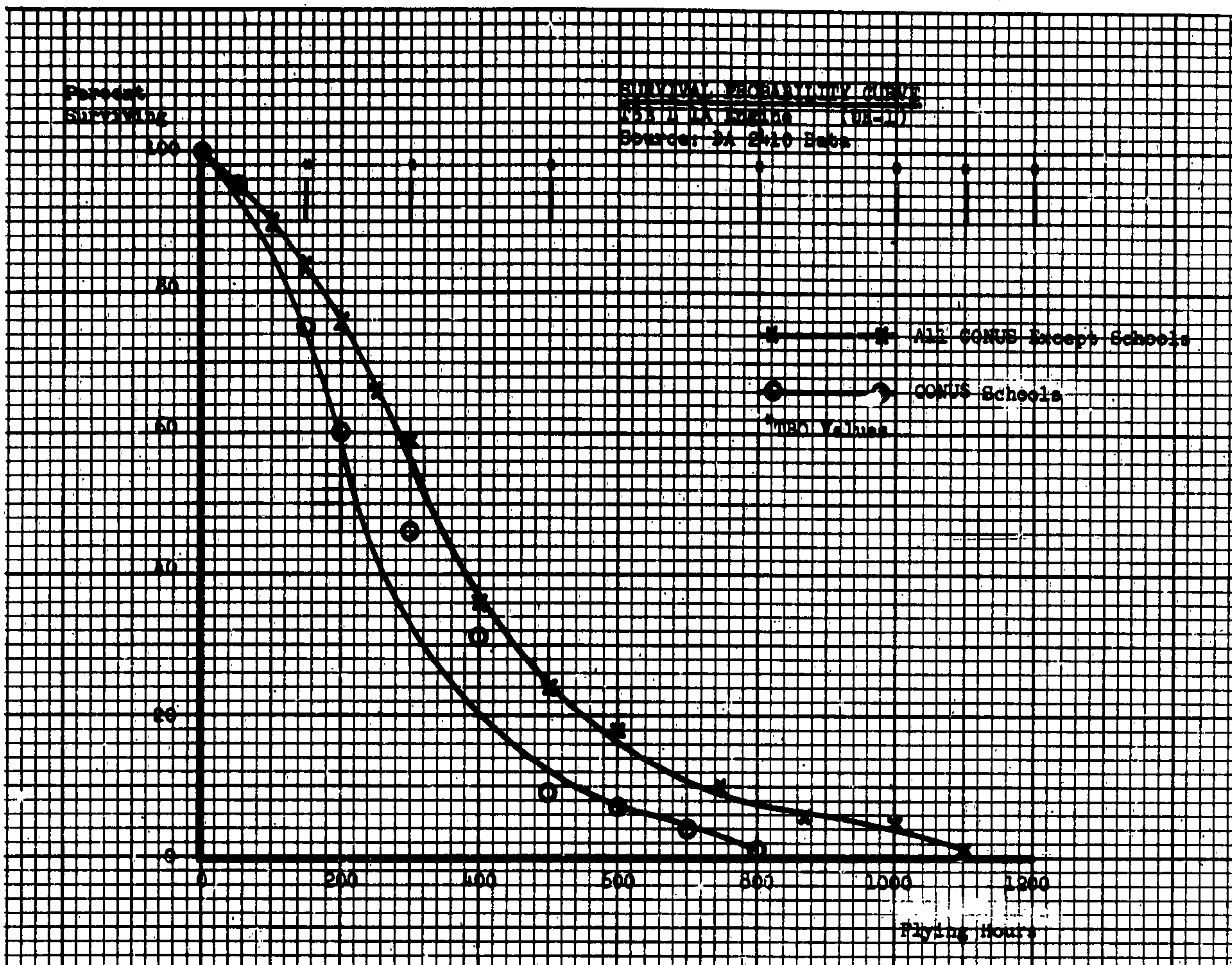

SURVIVAL PROBABILITY CURVE
Source: DA 2410 Data
Percent Surviving
100
80
60
40
20
0
0
200
400
600
800
1000
1200
Flying Hours
All CONUS Except Schools
CONUS Schools
*TBO Values

Figure 6.19

6.1.4 APPLICATION

Survival Probability Curves should, as much as possible, be compiled separately for major theaters of operation, since factors such as climate, mission, and operating level may have an important effect on the relationship between failures and flying hours.

Survival Probability Curves should be compiled separately for overhaul removals and for combined overhaul plus repair removals. The Survival Probability Curve for overhaul is used to forecast the number of removals for overhaul, the Survival Probability Curve for overhaul and repair combined is used to forecast the total number of removals; the difference is the forecast of the number to be repaired.

Figure 6.20 shows the complete forecasting cycle in greater detail. The starting point is a file of flying hour histories covering all items that were installed at any time during the previous year. This file takes the form of Table X in the previous example. Maintaining this file of item histories requires that the number of flying hours logged on a specific component be available through a system of cross-reference between the item serial number and the tail number of the aircraft on which the item is installed. In this file, removals should be classified as either in-area repair, NICP repair, or overhaul.

A computer run performed with the Item Histories File as input produces "raw" actuarial failure rates, plots the results of the computation in the form of Survival Probability Curves, and prints the fraction of removals for repair which was repaired in the area itself.

It is recommended that AVCOM establish a Major Components Life Committee, consisting of engineers, reliability experts, and commodity managers to analyze these plots and to project smoothed Survival Probability Curves for the next fiscal year by area if significant differences between areas appear to exist. These survival probabilities, together with next year's flying hour program and the current ages of installed items form the input to a computer run which produces the number of overhaul removals and repair removals (if any) expected for the next year. It is proposed that the U.S. Army Maintenance Board assist AVCOM in estimating which fraction of the repair removals can be absorbed in the respective areas without the need for evacuation.

Using next year's TOTAL projected Survival Probability Curves, the computer plots the Overhaul Ratio curve; the overhaul ratio is the ratio between the failure rate for overhaul only and the failure rate for all removals; it indicates which portion of failures in a certain age interval will be overhauled rather than repaired. Naturally, if all removals are overhauled and repair does not apply to the item under consideration, this curve is unnecessary. The Major Components Life Committee, considering the current reliability information available and the Product Improvement programs under way or contemplated, projects the Survival Probability Curve (overhauls only) and the Overhaul Ratio curve for five years in the future. These curves are then used to compute the actuarial Mean-Time-Between-Overhauls and Mean-Time-Between-Removals, which, together with the projected average flying hours per aircraft and the number of aircraft form the basis for estimates of repair and removal rates.

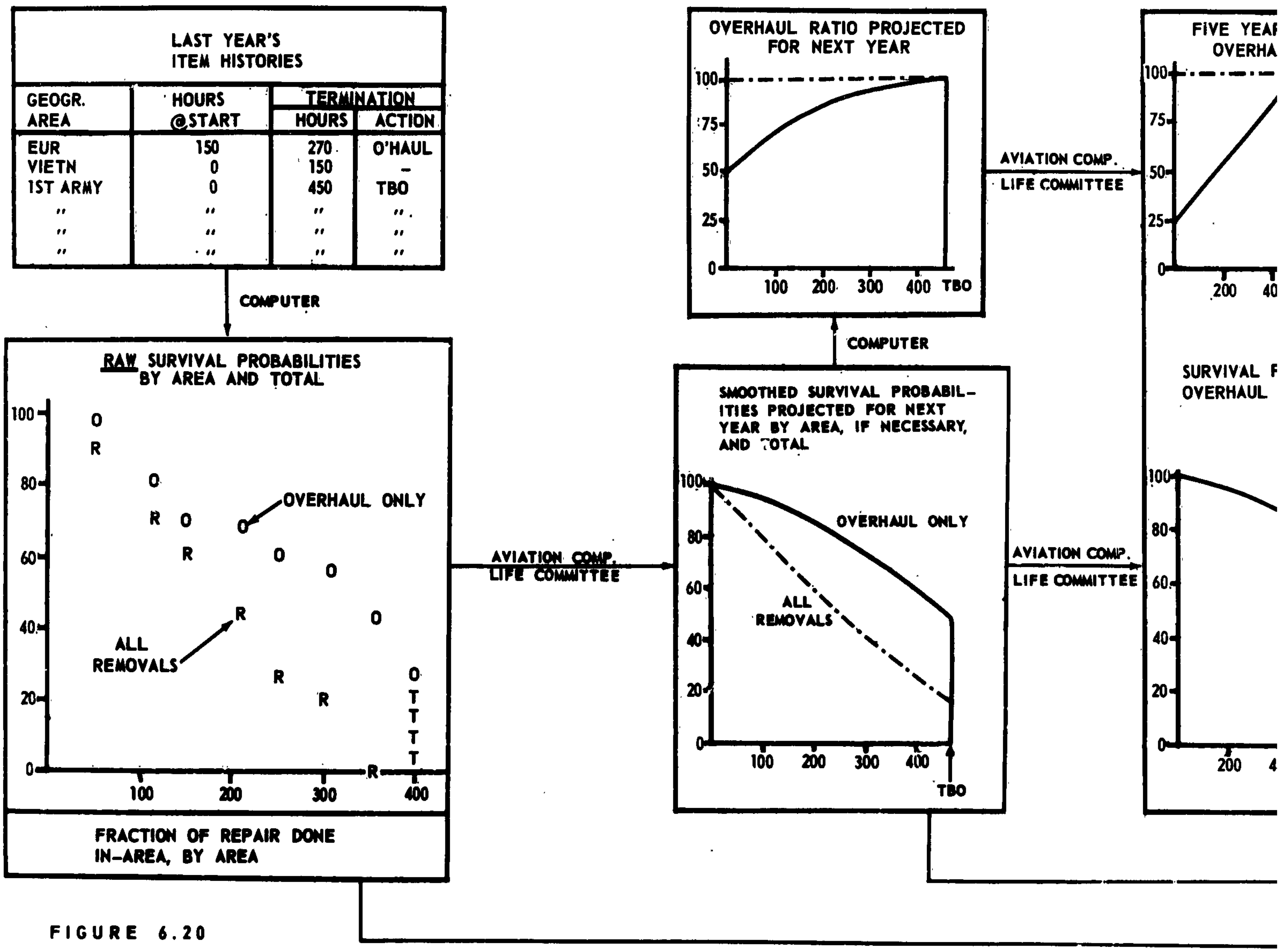
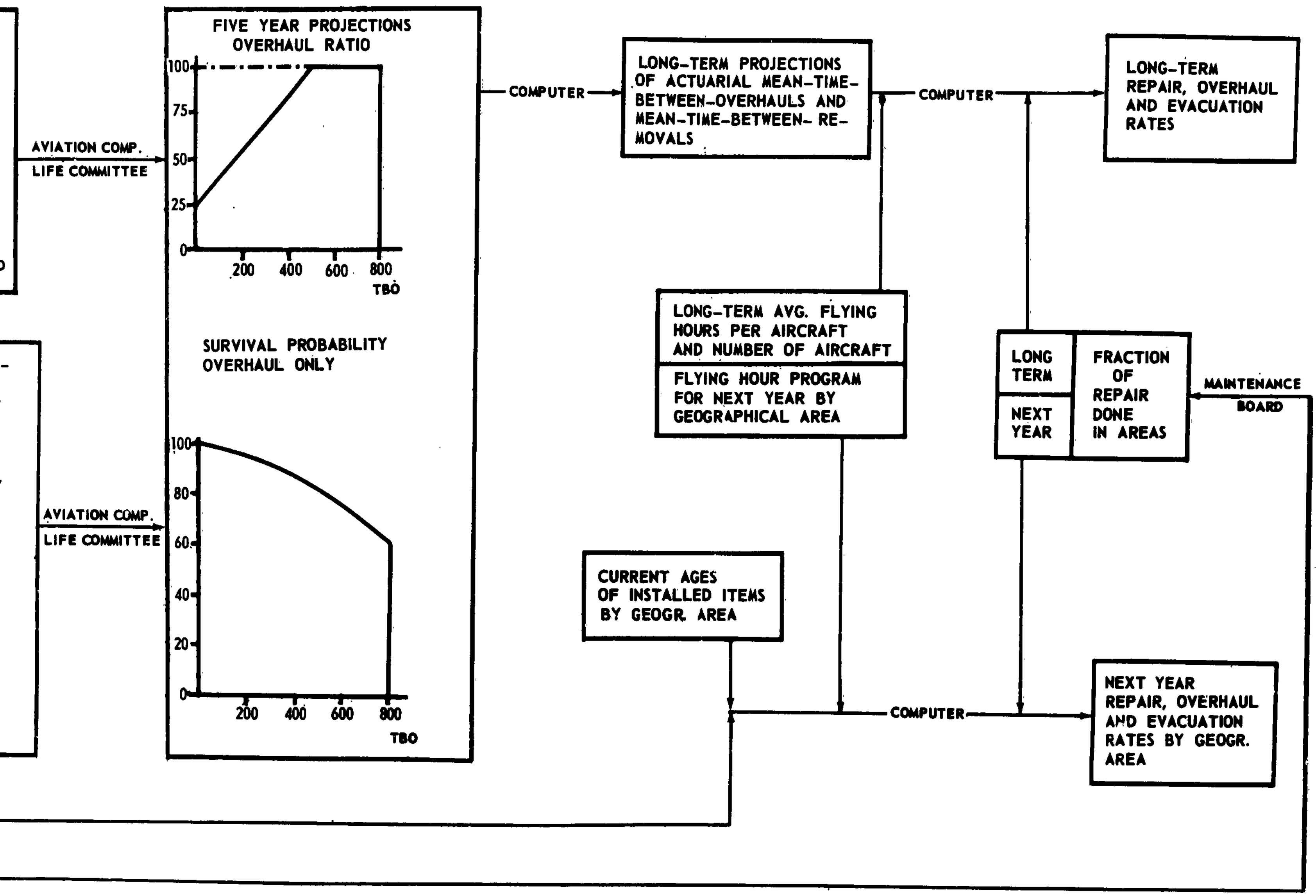

LAST YEAR'S ITEM HISTORIES
GEOGR. AREA
HOURS @START
TERMINATION
HOURS
ACTION
EUR 150 270 O'HAUL
VIETN 0 150 –
1ST ARMY 0 450 TBO
COMPUTER
RAW SURVIVAL PROBABILITIES BY AREA AND TOTAL
100
80
60
40
20
0
100
200
300
400
OVERHAUL ONLY
ALL REMOVALS
FRACTION OF REPAIR DONE IN-AREA, BY AREA
AVIATION COMP. LIFE COMMITTEE
SMOOTHED SURVIVAL PROBABILITIES PROJECTED FOR NEXT YEAR BY AREA, IF NECESSARY, AND TOTAL
OVERHAUL ONLY
ALL REMOVALS
TBO
COMPUTER
OVERHAUL RATIO PROJECTED FOR NEXT YEAR
75
50
25
TBO
AVIATION COMP.
LIFE COMMITTEE
SURVIVAL
OVERHAUL

FIGURE 6.20

The Forecasting Cycle



6.2 THE WORLD-WIDE INVENTORY MODEL

The world-wide inventory model presented in this section is a mathematical description of the major elements in the supply and maintenance system for high-value aircraft components. It brings such important systems parameters as removal rates, pipeline times, and the number of spares, under one common denominator, that of operational readiness of the aircraft population to be supported. This model forms the basis for the Supply Control Study. One might describe the Supply Control Study as the Supply Analyst, or Commodity Manager, manipulating the Inventory Model, exploring the different courses of action open to him and their effect on the system. It enables him to compute the number of spares required to achieve a specified level of supply performance or to compute the level of performance which can be attained with a given number of spares; he can investigate the effects of changes in removal rates, pipeline times, etc.

The model takes advantage of the unique one-to-one relationship between requirements for serviceable spares and the generation of unserviceables. Normally, in peace-time operations, only negligible quantities are involved in attrition losses. An engine can practically always be overhauled and returned to serviceable condition. Apart from procurement, the system can be considered as a closed loop: a certain number of items is locked up in this loop, cycling between usage, unserviceable stock, overhaul or repair, and serviceable stock (Figure 6.21). The complete cycle can be considered as consisting of two sections, the NICP section (dotted lines) and the Area section (solid lines). The NICP section includes the "repair cycle" from evacuation of an item until it has been returned to serviceable condition, plus the serviceables on hand under NICP custody ready for shipment to one of the geographical areas. The Area section encompasses the actions necessary to replenish the area's serviceable stock after a component has been removed, indluding the replenishment pipeline from the NICP and the local repair pipeline.

6.2.1 THE STATISTICAL NATURE OF REMOVALS

Of critical importance is that the number of removals, and thus the number of demands for replenishment, shows unpredictable fluctuations from one month to the next. This is especially true for the individual areas even though the demand placed upon the system as a whole may be fairly stable. The first step in building a model, then, is an analysis of these "unpredictabilities". A round-about but very effective approach to this

SCHEMATIC FLOW OF AIRCRAFT COMPONENTS

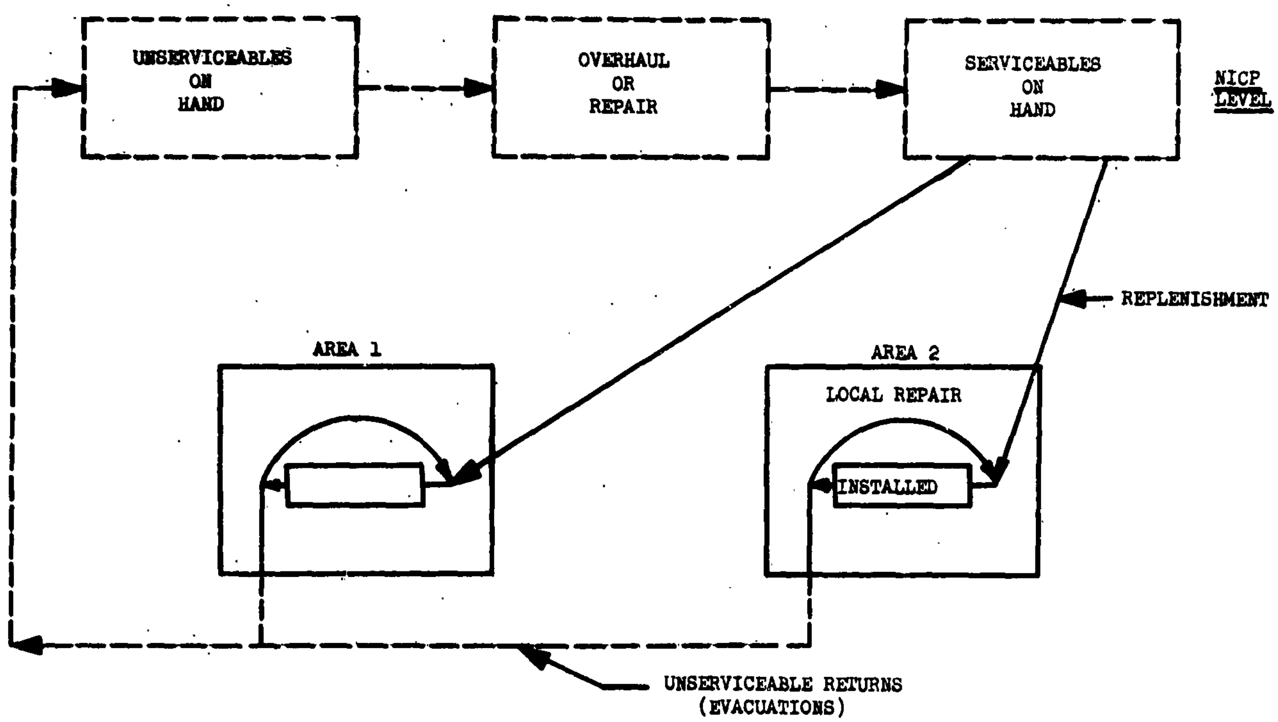


Figure 6.21

problem is to study how long it takes before the next removal takes place in a certain group of aircraft counting from the previous removal and to draw inferences from the variations in these time intervals. Examples of the statistical nature of calendar time intervals between successive removals are shown in Figures 6.22 through 6.27. These figures were obtained by plotting the number of intervals which exceed a certain number of days as a fraction of the total number of intervals observed.

That these points follow more or less a straight line on semi-logarithmic paper indicates a so-called random pattern of removals resulting in time intervals which fit an exponential probability distribution. This random pattern of removals is not unexpected in view of the variability of the hours flown by a number of individual aircraft in a given time period. The exponential probability distribution of time intervals between removals implies that the number of removals from a group of aircraft in a given period of time follows the "Poisson" probability distribution. An example of the Poisson probability distribution is shown in Figure 6.28; with an average of two removals per month we can say that in any given month:

the	probability	of 0	removals	is	14%
"	"	" 1	"	"	27%
"	"	" 2	"	"	27%
"	"	" 3	"	"	18%
"	"	" 4	"	"	9%
"	"	" 5	"	"	4%
"	"	" 6	"	"	1%, etc.

It is exactly this statistical nature of the occurrence of removals which makes it impossible to prevent stock-outs at all times and in all places. Carrying more spares reduces the incidence of stock-outs, but at a substantial cost, and it is therefore imperative to develop a meaningful measure of supply performance for the system as a whole.

The ability to support a certain state of readiness of the aircraft population depends directly upon the average waiting time experienced by removing organizations because a serviceable replacement item is not immediately available in their geographical area. Removing organizations may have to wait varying lengths of time depending upon whether:

CALENDAR DAYS BETWEEN REMOVALS
T 53 L 1A Engine Source: ERS Data

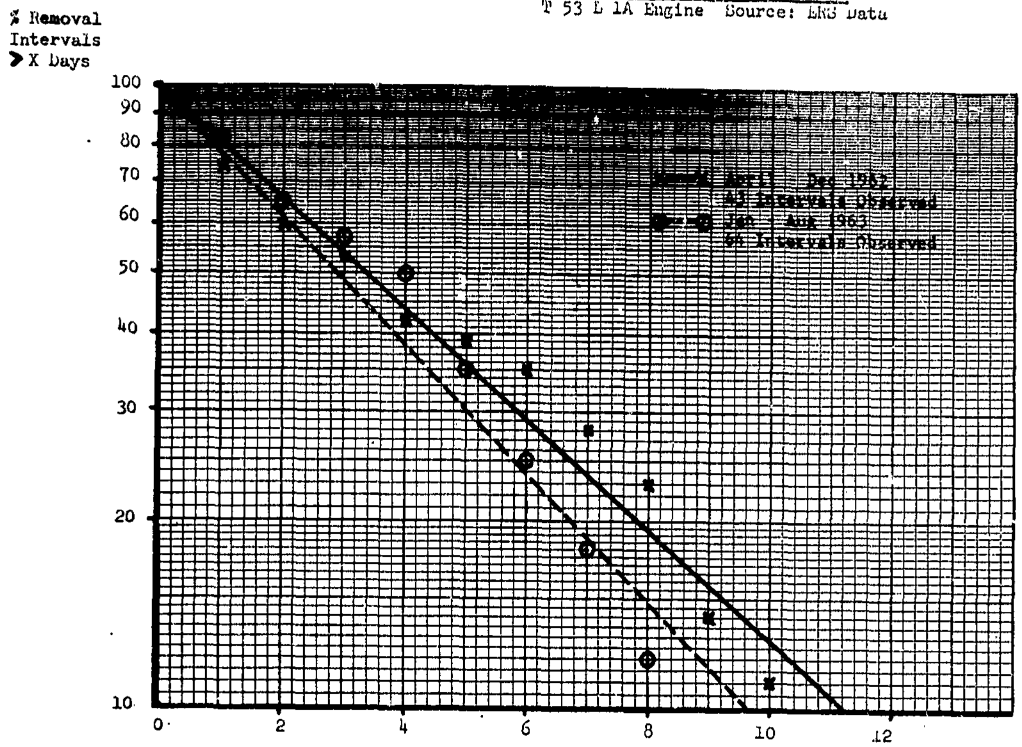


Figure 6.22

CALENDAR DAYS BETWEEN REMOVALS
Source: DA 2410 Data

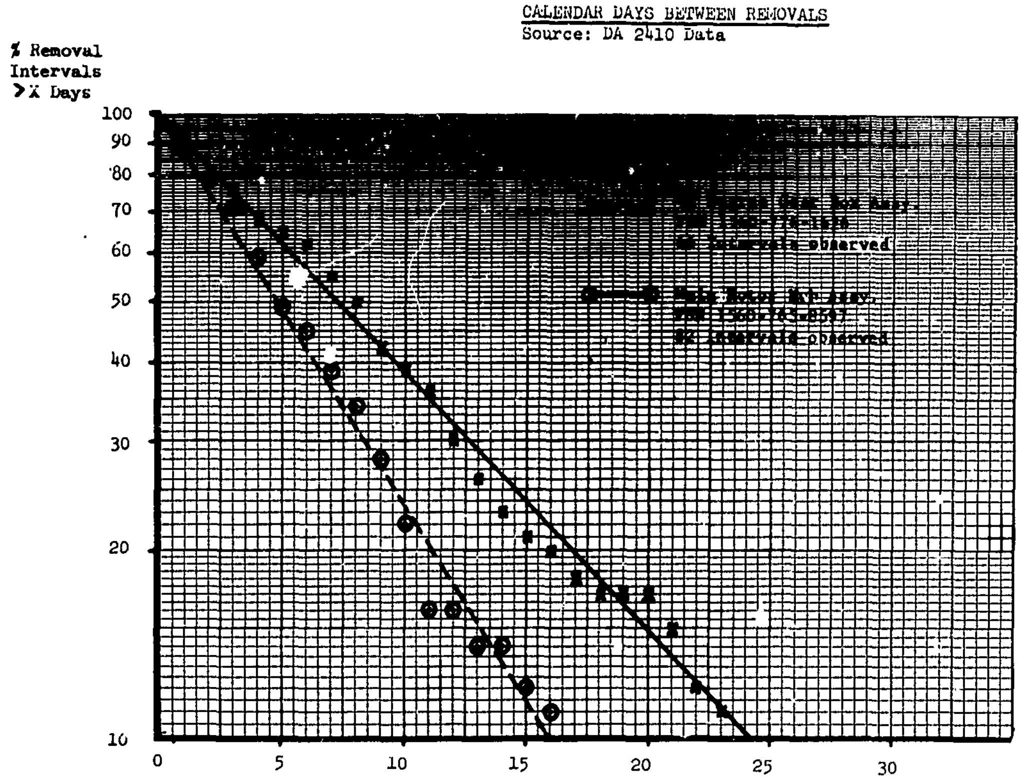


Figure 6.23

CALENDAR DAYS BETWEEN REMOVALS
O-335-6, -6B Engine Source: ERS Data

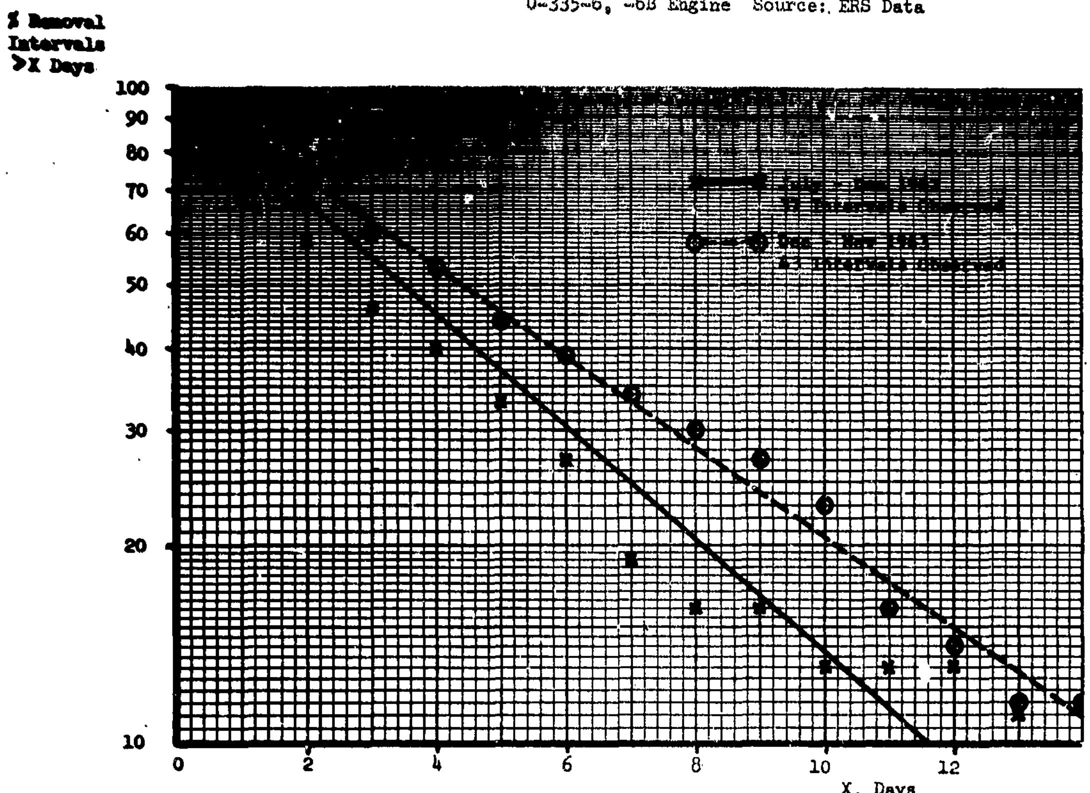


Figure 6.24

CALENDAR DAYS BETWEEN REMOVALS
R1820-84A Engine Source: ERS Data

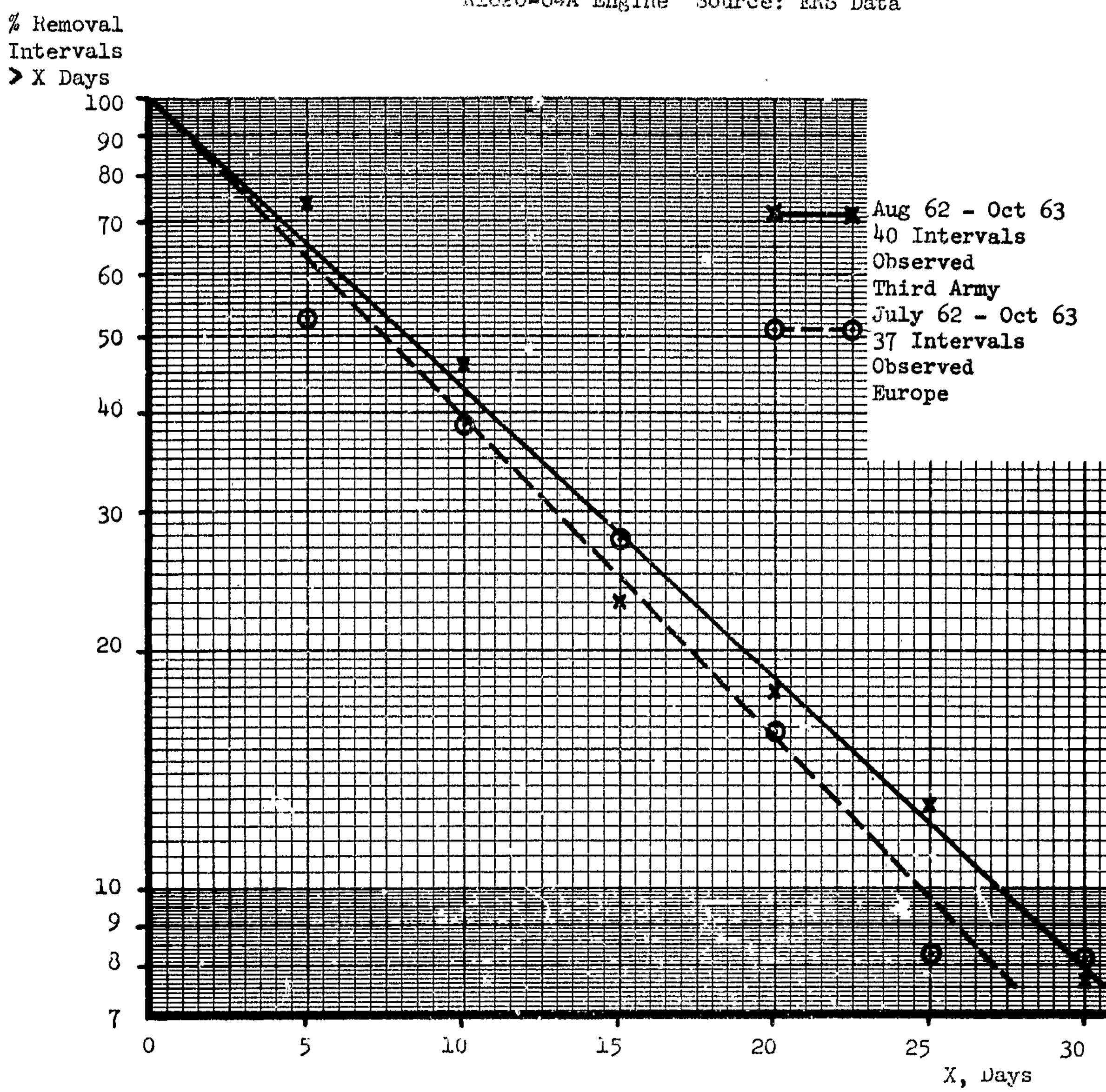
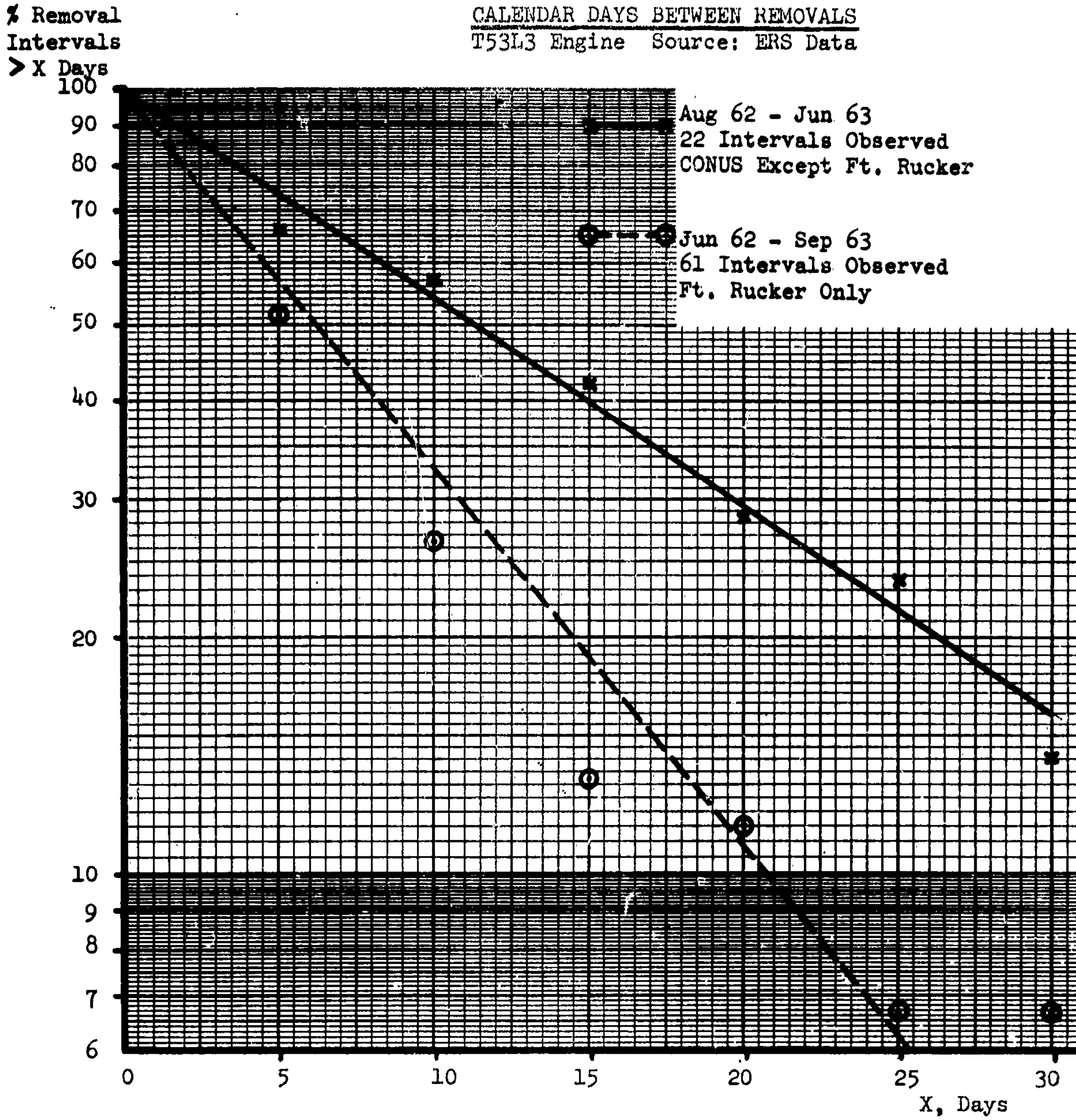
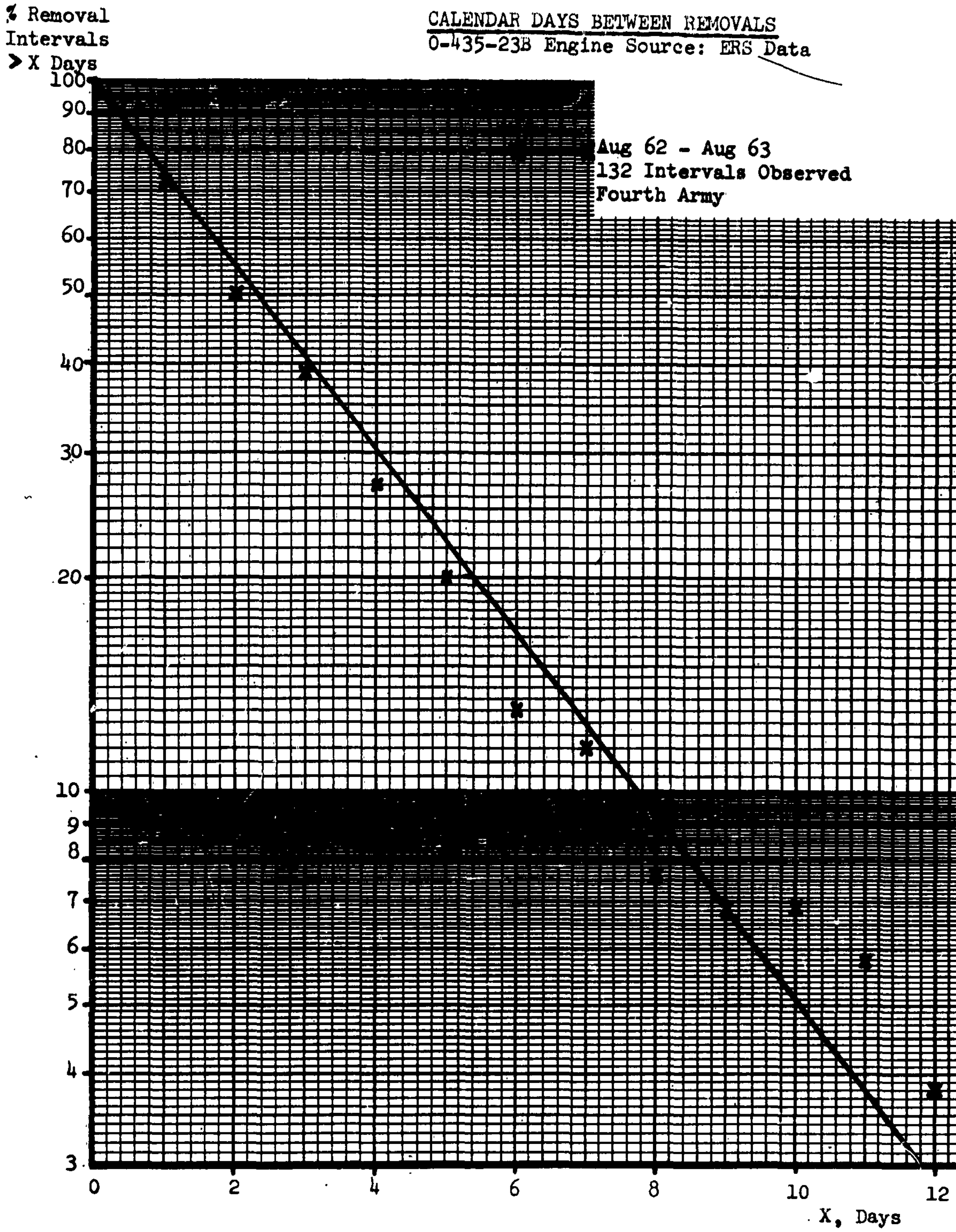


Figure 6.25



% Removal Intervals > X Days
CALENDAR DAYS BETWEEN REMOVALS
T53L3 Engine Source: ERS Data
Aug 62 - Jun 63
22 Intervals Observed
CONUS Except Ft. Rucker
Jun 62 - Sep 63
61 Intervals Observed
Ft. Rucker Only
100
90
80
70
60
50
40
30
20
10
9
8
7
6
0
5
10
15
20
25
30
X, Days

Figure 6.26



% Removal Intervals > X Days
CALENDAR DAYS BETWEEN REMOVALS
0-435-23B Engine Source: ERS Data
Aug 62 - Aug 63
132 Intervals Observed
Fourth Army
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
0
2
4
6
8
10
12
X, Days

Figure 6.27

EXAMPLE OF POISSON DISTRIBUTION

AVERAGE = 2

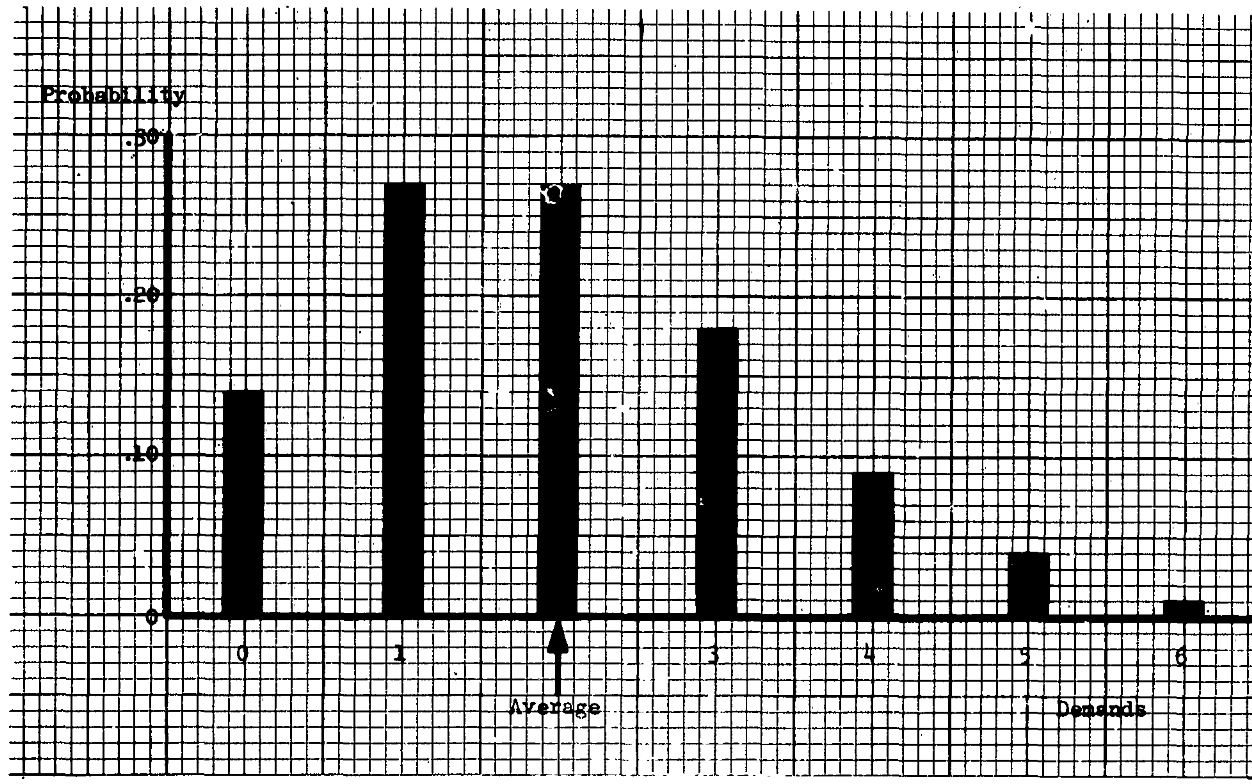


Figure 6.28

(1) an unserviceable item is already under repair in the area

(2) a serviceable item is already in transit from the NICP

(3) emergency action is taken to replenish the area

Zero waiting times when an item is already on hand are to be counted into the average waiting time. If, for instance, in 75 out of 100 removals an item is on hand, but in 15 cases the wait is 5 days and in the remaining 10 cases the wait is 10 days, then the average wait would be 1.75 days. This may not be very meaningful to the few who have to wait 10 days for a replacement item, but it is nevertheless clear that this average is of great importance. The longer the average wait is, the more aircraft will be grounded for lack of these components on the average. For example, if a certain fleet of aircraft uses 200 engines per year, then 1.75 days average wait means that on the average there is always one plane grounded, waiting for an engine. But if the average wait is cut in half, only one-half of the time will there be a plane grounded, on the average.

In the following sections will be shown how the Poisson probability distribution of removals can be used to compute the average customer wait which is the proposed measure of supply performance.

6.2.2 AVAILABILITY AT THE NICP LEVEL

The function of serviceable on-hand items under NICP custody is to protect the NICP against stock-outs resulting from variations in the rate of demands, combined with a time lag in getting items removed for overhaul back into serviceable condition. If the rate of demands upon the NICP were constant (say always one item per month), even if it takes one year to return the removed item to serviceable condition, the NICP would not need any serviceable stock on hand because items returning to serviceable stock (overhaul) and items leaving serviceable stock (demands) would be perfectly matched. The same would hold true if items could be made serviceable immediately upon removal from the aircraft no matter what the fluctuations of demand because a failure would at the same moment create a new serviceable item. In reality, however, we are faced with a demand pattern following the Poisson distribution as well as a long repair cycle time.

It can be shown that the number of items in the NICP repair cycle (between removal and completion of overhaul) is on the average equal to the average repair cycle time multiplied by the average total evacuation rate, but that it fluctuates around this average according to the Poisson distribution. If at times the number of these unserviceables exceeds the stock level assigned to the NICP section of the system, then the NICP is out of stock, meaning that replenishment shipments to the areas are delayed. Given the NICP stock level, the average number of evacuations per year and the average NICP repair cycle time, the Poisson distribution enables one to compute the frequency and seriousness of these stock-out periods and from this, how long demands for replenishment shipments are delayed on the average. Figure 6.29 shows how this average delay depends on the NICP stock level for 100 removals per year and a 6 month repair cycle.

One simplifying assumption which is made in these computations is that the four different CONUS depots which together physically store serviceable items can be considered as one inventory. The NICP is not assumed to be out-of-stock as long as a serviceable item is still to be found in one of the depots. The result of this simplification is to somewhat overstate the supply position of the NICP.

6.2.3 AVERAGE CUSTOMER WAIT IN AN AREA

Similarly, the inventory assigned to the area section of the system serves the purpose of protecting the areas against stock-outs resulting from variations in the rate of demands for replacement items combined with time lags for local repair and for replenishment shipment from the NICP. It can be shown that the average number of items tied up in the area's pipelines equals the average removal rate for the area multiplied by the weighted average of in-area repair cycle time and replenishment time, but at any one time fluctuates around this average according to the Poisson distribution. Here it is important to realize that an evacuation of an unserviceable item from the area may not immediately be followed by a replenishment shipment from the NICP because, as has been discussed in the previous section, the NICP does not always have serviceables on hand. Thus the replenishment time used in the computation equals the average shipping time from NICP to the area plus the average delay in filling demands for replenishment shipments at the NICP level.

A stock-out in the area inevitably results if at any time the number of items tied up in the area's pipelines exceeds the Area Inventory Level. One can compute how frequently and to what extent this will happen and from this what the average customer waiting time will be.

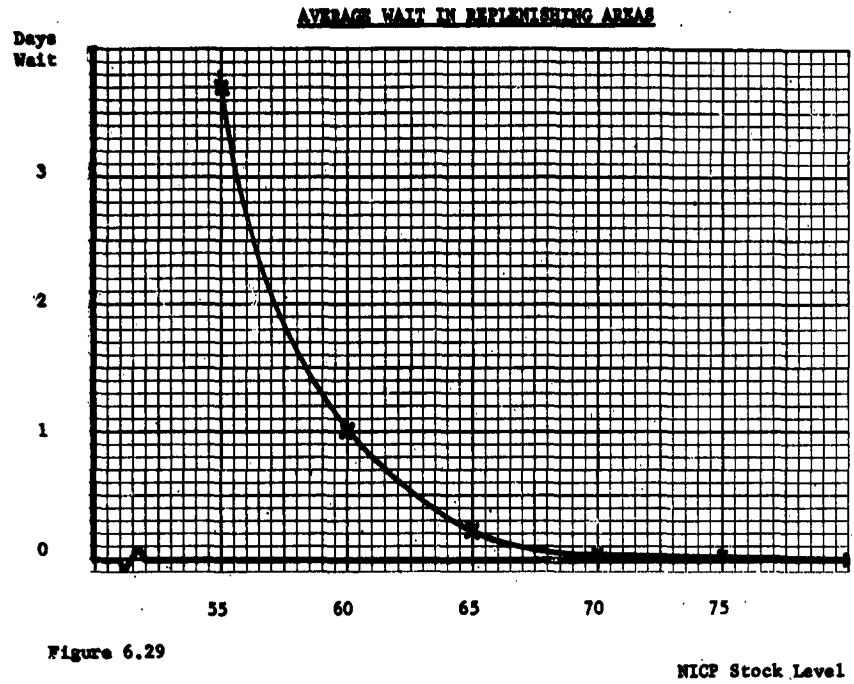


Figure 6.29

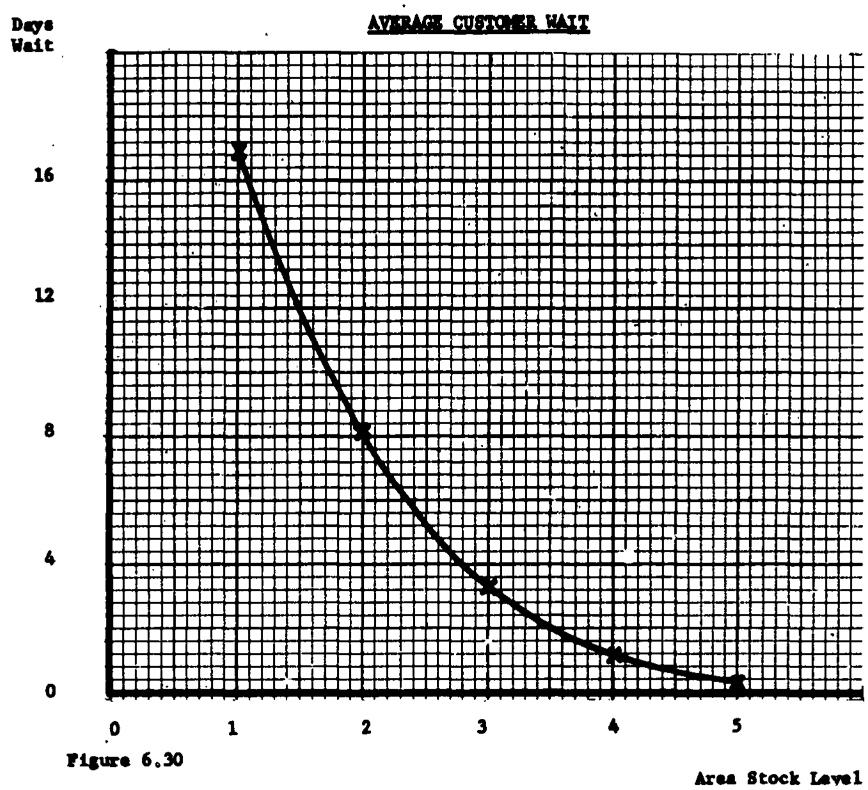


Figure 6.30

Figure 6.30 shows how the average customer waiting time in an area with an average of 12 removals per year and an average replenishment time of 2 months (no in-area repair) depends on the Area Inventory Level.

The computations required to find the average customer wait are schematically shown in Figure 6.31. Appendix C contains the necessary mathematical background.

6.2.4 APPLICATION

The computation of an area's average customer wait can be used to answer some important management questions, such as how many spares should be allocated to a certain area and how many spares should be carried in total.

Optimal Distribution of Available Spares: There should be some best way to distribute spares over the different areas and the NICP section of the system if the total number of spares is limited. This "optimal" distribution pattern involves careful consideration of trade-offs between the areas individually: how much does one area benefit from an increased inventory level compared to another, and what is it worth to improve the performance in one area as compared to another? In addition the NICP stock level has to be balanced against the field stock level: is it better to raise the NICP stock level thus improving the level of availability to all areas, or would the same amount of stock do more good if used to increase the Area Inventory Levels?

The "optimum" is obtained if:

1. Subtracting one unit from any one area's inventory level and adding it to some other area will result in a longer average wait for the system as a whole.

2. Subtracting one unit from the NICP stock level and adding it to an area, no matter which one, will have the same effect.

One can zero in on this situation with the following method:

1. Start with allocating all spares to the NICP section of the system; all Area Inventory Levels are zero. Compute the average customer wait for the system as a whole.

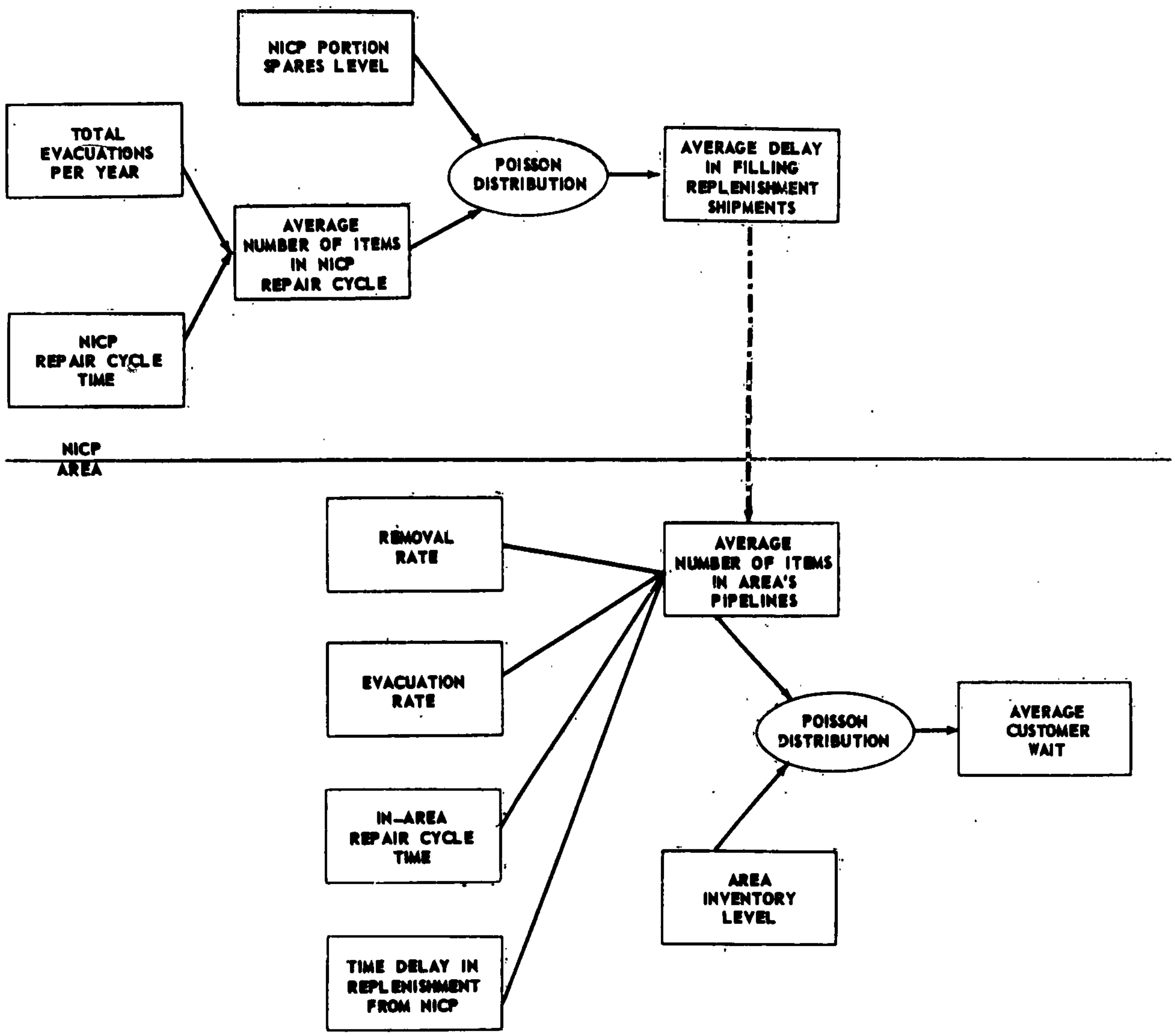

NICP PORTION SPARES LEVEL
TOTAL EVACUATIONS PER YEAR
POISSON DISTRIBUTION
AVERAGE DELAY IN FILLING REPLENISHMENT SHIPMENTS
AVERAGE NUMBER OF ITEMS IN NICP REPAIR CYCLE
NICP REPAIR CYCLE TIME
NICP
AREA
REMOVAL RATE
AVERAGE NUMBER OF ITEMS IN AREA'S PIPELINES
EVACUATION RATE
POISSON DISTRIBUTION
AVERAGE CUSTOMER WAIT
IN-AREA REPAIR CYCLE TIME
AREA INVENTORY LEVEL
TIME DELAY IN REPLENISHMENT FROM NICP

FIGURE 6.31

2. Compute the average customer wait if one unit were taken from the NICP stock level and added to the first area. Repeat for the second area, third area, etc.

3. Determine the one area to which the unit should be added for best results by comparing the results obtained sub. 2). Does this improve the average wait compared to what it was with the unit still at the NICP? If so, make that transfer and return to 2). If not, then the optimum has been reached and no further improvement is possible.

This procedure has been programmed for a high-speed electronic computer producing the answer in a matter of minutes. This computer program can easily be adapted to the AVCOM data processing installation. For details see Appendix C.

The Desired Inventory Level: The above-mentioned procedure enables one to compute the shortest customer wait which can be obtained with a given number of spares for the system as a whole. A natural extension of this analysis is to investigate the effect on the average customer wait if the number of spares is changed. By starting with a small number of spares and adding to it until the additional improvement in customer wait no longer warrants the cost of the additional items one can decide how many spares should be carried.

Other Uses: The World-Wide Inventory Model lends itself equally well to analysis of factors other than the total number and geographical distribution of spares. It may be used, for instance, to investigate the effects of lower removal rates resulting from a TBO extension, or the effect of shorter pipeline times possible with high-speed transportation.

6.2.5 RESULTS AND CONCLUSIONS

Experimentation with the model has shown that the distribution of available spares is a key factor in the performance of the system. Order of magnitude improvements in the waiting time of field customers are possible compared with a policy of setting arbitrary NICP or Area safety stock levels. The following example illustrates this point.

The particular item under consideration is a helicopter gas-turbine engine in use in nine different geographical areas, 5 in CONUS and 4 overseas. The following table summarizes pertinent data on aircraft dispersion, flying hours, and removals:

Area	No. of Aircraft	Hrs. per A/C per month	Removals per year	Local Repairs per year	Evacuations Repair	Evacuations O'Haul
2nd Army	28	22	19	2	4	13
3rd Army	373	36	417	35	104	278
4th Army	24	30	23	2	6	15
5th Army	17	16	9	1	2	6
6th Army	22	22	15	1	4	10
EUROPE	118	24	89	6	24	59
ALASKA	10	12	3	-	1	2
KOREA	15	22	10	-	3	7
VIETNAM	237	47	345	-	115	230
TOTAL	844		930	47	263	620

Current pipeline times are assumed as follows:

CONUS:	serviceable replenishment from NICP	30 days
	unserviceable return to ARADMAC	40 days
	local repair cycle	15 days
OVERSEAS:	serviceable replenishment from NICP	
	for EUROPE, ALASKA, and KOREA	65 days
	for VIETNAM	55 days
	unserviceable return to ARADMAC	90 days
	local repair cycle (SANDHOFEN)	50 days
ARADMAC:	overhaul	100 days
	repair	60 days

The computed average wait under optimal allocation of spares level as shown in Figure 6.32, solid curve, and below:

No. of spares:	480	490	500	510	520	530
Days avg. wait:	3.85	2.32	1.32	.70	.34	.15

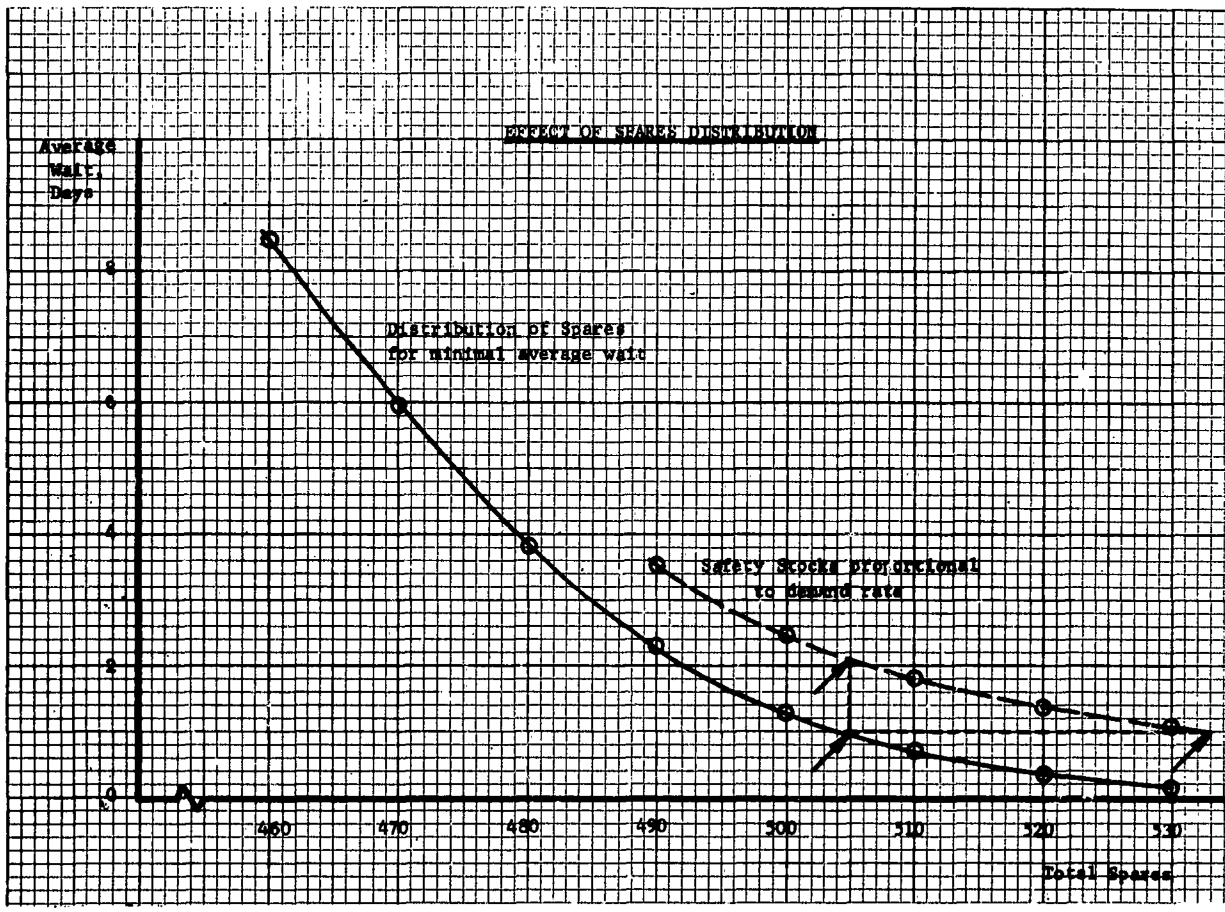

EFFECT OF SPARES DISTRIBUTION
Average
Wait,
Days
8
6
4
2
0
Distribution of Spares
for minimal average wait
Safety Stocks proportional
to demand rate
460
470
480
490
500
510
520
530
Total Spares

Figure 6.32

Had we allocated the available safety stock proportional to the demand rates for the different areas and for the NICP, however, we would have found a different relationship, represented by the dotted curve in Figure 6.32:

No. of Spares:	490	500	510	520	530
Days avg. wait:	3.54	2.51	1.81	1.38	1.08

With 505 spares, for instance, the average customer wait is 2 days where it could have been only 1 day if the spare engines are allocated for maximal effectiveness. To obtain a comparable level of supply performance under the proportional safety stock rule would require an additional 28 engines! In this example protection against stock-outs at the NICP level is unwarranted. By taking the protective stock away from the NICP and using it to increase the protection against stock-outs at the field level the performance of the system as a whole is significantly improved.

6.3 THE SUPPLY CONTROL STUDY

As stated in Section 2.3, the Supply Control Study is done coincident with the budget cycle or when major revisions to program factors occur. Its major purposes are to provide:

(1) a long-term projection of the number of spares needed when aircraft have been fully deployed, when failure rates have stabilized with TBO's extended to their maximum feasible values, and when pipeline times have been reduced to desired target values.* This number of spares, the "Desired Inventory Level", is based on achieving a specified degree of customer service.

(2) a projection for the next fiscal year of:

- (a) the number of removals that will result in repair and overhaul
- (b) the degree of customer service that can be achieved with the currently available spares
- (c) the reduction in pipeline times needed to provide a given degree of customer service with the current number of spares
- (d) the additional spares needed, if current pipeline times are not improved, to provide a given degree of customer service
- (e) the number of spares to be allotted to each customer area, calculated for maximal customer service world-wide

These outputs of the Supply Control Study are used by Commodity Managers as the basis for recommending for the next fiscal year:

(1) the size of the repair, overhaul and modifications programs to be supported

(2) the number of spares to be procured or retired

(3) changes in pipeline time standards or targets

(4) changes in authorized Area Inventory Levels

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*Long-term will normally be taken to mean: 5 years from today.

STEPS IN COMPUTATION OF
SUPPLY CONTROL STUDY

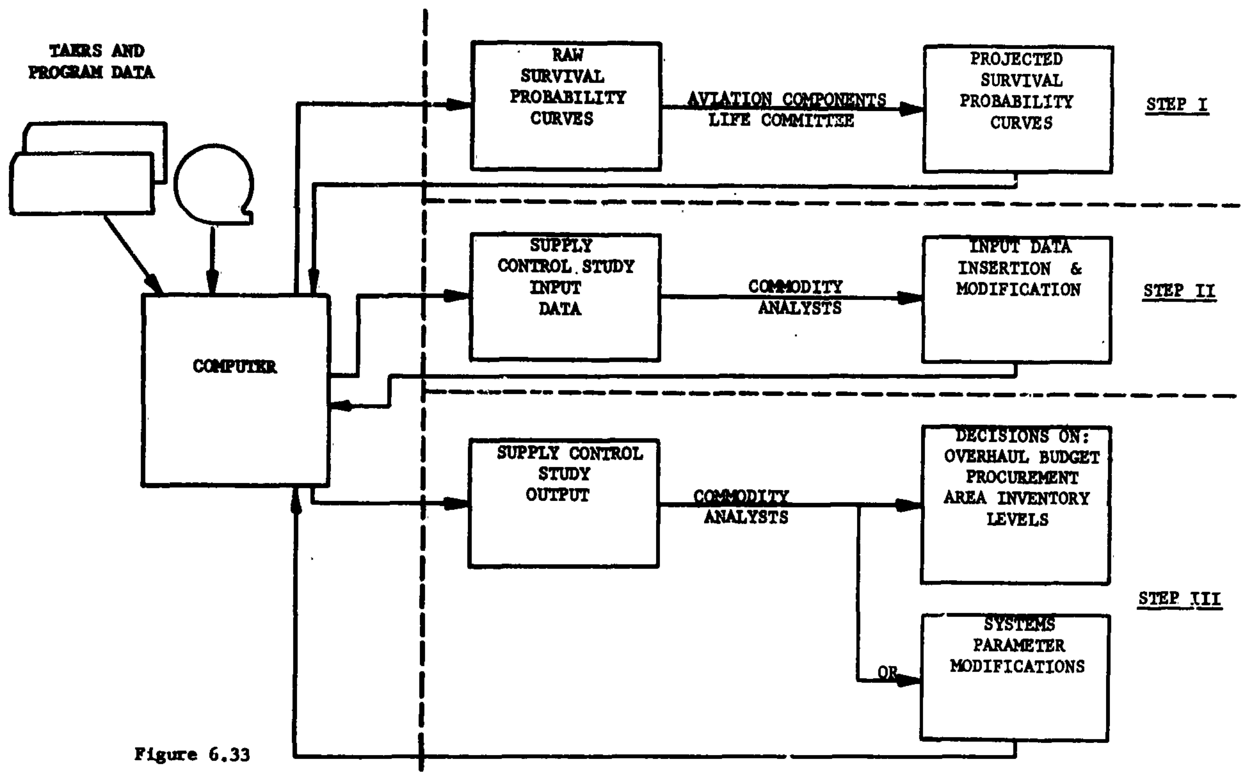

Figure 6.33

6.3.1 FORMATS

The Supply Control Study is done in three steps, each of which involves communication between the computer and the analyst. This process, which is graphically illustrated in Figure 6.33, can be summarized as follows:

Step I: Projection of Survival Probability Curves: The first step consists of computer processing of historical failure data and data on component operating hours to produce raw survival probability estimates. The Aviation Components Life Committee uses these estimates as the starting point to project component reliability into the future. These procedures are described in detail in Section 6.1. If the Actuarial procedure is not used, a projection of the Mean-Time-Between Overhauls and Mean-Time-Between-Removals would be made at this point.

Step II: Preparation of Input Data for the Supply Control Study: A set of input data is printed out initially by the computer for review by the Commodity Analyst prior to calculation of the Supply Control Study. The purpose of his review is to insert the most recent program data, and to compare current pipeline values against standards, possibly leading to a modification of the values to be used in the study and to recommendations for changes in the standards. The additional input data are then key-punched for Step III, the computation and review of the Supply Control Study. Two sections of input data are required, the first for the long-term portion of the study and the second for the portion which deals with the next fiscal year (see Exhibit I). A description of the different data-elements entering into the Supply Control Study is given in Exhibit II. Item identification and other heading data have been excluded from this description and from Exhibit I.

Step III: Calculation of the Supply Control Study Output: After the additional and modified input data have been key-punched they are entered into the computer for the actual Supply Control Study computations. The calculations involved are those of the World-Wide Inventory Model and the Actuarial Forecasting procedure. Four sections of output are produced as shown in the output portion of Exhibit I:

Section 1 - Area Information: A separate line of output is printed for each CONUS and OVERSEAS area. The output generally takes the form of double columns, one showing the current value of the factor involved, the other showing the expected value for the next fiscal year.

Section 2 - NICP Summary: This section summarizes important information about the NICP level of operations. Current values are shown in addition to projected values for the next fiscal year and for the long term.

Section 3 - Phased Inventory Position: Total system requirements are developed on a time-phased basis and the performance that can be achieved with current assets and pipeline values is compared with what is desired in the long term. The analyst is also provided with output showing him the improvement in next year's performance that can be achieved with a higher number of spares or with shorter pipeline times. It should be noted that an increase in the number of spares may be only partially (or perhaps not at all) realized in the next fiscal year, either because of lead time or funding constraints. Furthermore, knowledge of what happens when the total pipeline time (including shipment of serviceables, shipment of unserviceables, and repair) is changed may not enable the Analyst to make specific recommendations. The effects of other actions, such as changes in TBO or repair policy, may also be of interest to the Analyst. In such cases, the pertinent input data would be modified, the Supply Control Study re-calculated, and the two sets of results used as the basis for the Analyst's recommendations.

Section 4 - Recommended Actions for the Next Fiscal Year: On the basis of his analysis of Sections 1, 2, and 3, the Analyst decides on the level of activity to be supported during the next fiscal year in terms of funding for overhaul, procurement, premium transportation, etc., and records these recommendations in this fourth and last section.

The output information is discussed by item in Exhibit II following the description of the input formats. The entire Supply Control Study is illustrated with a numerical example in the following Section 6.3.2.

6.3.2 A NUMERICAL EXAMPLE

Our example of gas-turbine engines, introduced in Section 6.2.5, is used again here for two purposes. The first purpose is to demonstrate the use of the proposed Supply Control Formats; the second purpose is to illustrate a dilemma with which Management almost always is faced involving the choice between what is best in the short-run as opposed to what is best in the long-run. But more importantly, in doing this we hope to impress the reader with the clarity of presentation which has been achieved in the proposed Supply Control Study.

Exhibit I, pages 1 through 4, contains all input for our example. The data provided initially by the computer are shown as printed on the form; the data filled in by the Analyst in completing the input forms is shown as handwritten. Starting with the long-term portion, pages 1 and 2, we find that the aircraft population is expected to increase from the present 844 to 1080 five years from now. The long-term number of flying hours is estimated at 30 per aircraft per month. The reliability of the item is fully characterized by the Mean-Time-Between-Removals (500 hours) and the Mean-Time-Between-Overhauls (700 hours). The projected TBO and the actuarial data is displayed also, but all calculations in the long-term portion of the Supply Control Study are based on the MTBO and MTBR values. The long-term demand breakdown provides for 5 CONUS areas, of which one is a particularly large one, and for 5 overseas areas, two large and three small. As far as CONUS areas are concerned we foresee that repair (as opposed to overhaul) of items will be taken care of within the areas without NICP intervention (this may involve CONUS Depot repair and return to area stock) in about one-half of the cases, the other half ending up at ARADMAC. As far as the overseas areas are concerned, local repair is estimated at 20% of all removals for repair, the rest evenly distributed between CONUS Depots (returned to NICP stock) and ARADMAC. Long-term pipeline times are assumed as shown on page 2. Relatively large improvements are expected in the ARADMAC repair and overhaul times, and in the evacuation from and replenishment of CONUS areas. Lesser changes are projected for overseas areas, and in-area repair cycles are not thought to be subject to much improvement at all. The desired level of customer service is set at one-half day average wait.

Pages 3 and 4 of the Exhibit I show the input pertaining to next year's operations. This is identical in all respects to the data presented in Section 6.2.5. Only the page for the 3rd Army area is shown, a complete set of pages would contain eight more of these "page 4" sheets, one for each of the other eight areas.

Turning now to the resulting output of the Supply Control Study, we find, on page 1*, that the world-wide total of removals for that year is estimated at 930, evacuations total 883, to fill the area replenishment cycle and repair cycle pipelines takes 108 engines, the NICP takes another 370 engines to fill its repair cycle, and thus, just to fill the system's pipelines takes 478 units (not even considering safety stocks) while the

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*To make the results of the computations stand out the current averages and Area R/O values have been omitted from this page. They would normally be printed out for comparison.

current inventory amounts to only 450. It is no wonder then, that next year's operations will be characterized by severe stock-outs: the average field customer waiting time is almost 12 days. Page 2 provides more insight into this problem. We find that in order to bring the average customer wait down to approximately the desired one-half day another 65 spares are needed, or the alternative would be to reduce the pipelines by about 13% overall. In facing this difficult situation we have to keep in mind that, at least according to the five-year projections, the present inventory of 450 spares is greatly in excess compared to the projected need of 340 spares.

This situation is not at all uncommon for items which are relatively new to the system. In the beginning, failure rates are high, and the TBO is set very low, giving rise to inflated requirements. Giving in to the pressures of providing for adequate spares support during the early stages of the life of an item can cause serious excesses later. In our example this situation is aggravated by the expectation of shorter turnaround times as time goes on. Providing a solution to this problem is a managerial responsibility which falls outside the scope of the Supply Control Study as a format for analysis. But it seems obvious that this problem can be attacked only by subjecting these newer items to some form of rapid transportation and overhaul, and to intensified control over pipeline times in general.

Even if the Supply Control Study cannot solve these managerial problems, it certainly puts all the relevant information at one's fingertips and actually highlights problems of this kind if they exist. It is hoped that the clear exposure of these problems will in time lead to more effective policies for dealing with them.

This method provides an easy way of up-dating averages without the need for keeping a long history, as is required when the method of moving averages is used. Moreover, the rate at which the exponentially smoothed average responds to new information can be easily revised by changing the value of α, the smoothing coefficient. With moving averages, this can be done only by changing the length of the base period, which is rather difficult in actual practice.

The value of α determines the weight that is given to the most recent observations in comparison with past history. For example, choosing a value of $\alpha = 1$ results in discarding all previous history and setting the new average equal to the latest observation (a one-month moving average in effect) for when $\alpha = 1$:

$$A_t = X_t$$

Similarly, choosing a value of $\alpha = 0$ results in the new information being ignored entirely, for when $\alpha = 0$:

$$A_t = A_{t-1}$$

which means that the new average equals the previous average. Actually, α can be selected to approximate any moving average base period one might choose. For example, exponential smoothing with $\alpha = 0.286$ gives the same results as a 6-month moving average. Similarly, $\alpha = 0.154$ gives the same results as a 12-month moving average.*

As an illustration of exponential smoothing, consider the following example of flying hours per aircraft per month. The average computed last month was 36 hours per aircraft per month. DA 1352 data show that an average of 30 hours per aircraft was flown this month. Then, the new average (with $\alpha = .25$) is:

$$\begin{aligned} A_t &= (0.25)(30) + (1-0.25)(36) \\ &= 34.5 \text{ hours per aircraft per month} \end{aligned}$$

*A discussion of the exponential smoothing technique and its application may be found in "Statistical Forecasting for Inventory Control" by Robert G. Brown, McGraw-Hill Book Co., Inc., 1959.

If we are smoothing an annual rate such as number of removals per year, the new month's observation has to be multiplied by 12 to convert it to an annual rate before smoothing. For example, if the annual number of removals computed last month was 300 and this month's observation is 30 removals, then the new smoothed average (using $\alpha = 0.25$), is

$$A_t = (12)(30)(0.25) + (1-0.25)(300)$$

$$= 315 \text{ removals per year}$$

If we are smoothing a pipeline time, another slight modification must be made to adjust for the fact that the number of pipelines times observed fluctuates from month to month. For example, the number of serviceable shipments made in each of the last 6 months on which shipping times are available may have been: 16, 31, 21, 34, 24, and 18. Then, if only 2 shipments were reported during this month, it would be incorrect to weigh this month's average, based on only these two shipments, as heavily as the averages of the preceding months, which are based on a much higher number of transactions.

This difficulty is avoided by smoothing also the monthly number of transactions and by modifying the smoothing coefficient α by the ratio of the observed number of transactions in the current month to the average number of transactions per month. If we let

n_t = number of pipeline time transactions observed this month

λ_t = average monthly number of pipeline transactions this month

t_i = the individual pipeline times observed this month

then the equation for the average pipeline time becomes

$$A_t = \alpha \frac{n_t}{\lambda_t} \frac{\Sigma t_i}{n_t} + (1 - \alpha \frac{n_t}{\lambda_t}) A_{t-1}$$

with $\lambda_t = \alpha\, n_t + (1 - \alpha)\, \lambda_{t-1}$

Consider, for example, the following data for the unserviceable shipping time from an overseas area to a CONUS depot:

λ_{t-1} = 18 = the average monthly number of transactions

A_{t-1} = 70 days = the average length of this pipeline time segment, as computed last month

t_i's : 65, 84, 100, 68, 90, 64 days = the pipeline times observed during the current month

First, find λ_t, the new average number of transactions per month (α = .25):

$$\lambda_t = (0.25)(6) + (1-0.25)(18) = 15$$

Then, find A_t, the new average pipeline time

$$A_t = \frac{0.25}{15} (65 + 84 + 100 + 68 + 90 + 64) + (1 - \frac{6 \times .25}{15}) \; 70 = 70.9 \text{ days}$$

Figure 6.34 shows how the exponential smoothing method tracks a fluctuating series of observations of average hours flown per aircraft per month. The average number of hours flown per aircraft is about 20 per month for the whole 12-month period. The observations are taken from a table of random numbers, and fluctuate between 15 and 25 hours per month.

6.4.2 FORMATS

The formats of the Monthly Review and a description of the elements of information contained in each of its five sections are shown in Exhibits III and IV, respectively. The first three sections of the report depict the forecast (or standard) values of the program factors and other system parameters we are interested in, and the actual or "smoothed" average values as they exist at the time the report is prepared. The fourth section of the report shows how the total inventory is distributed geographically and gives the number of items in each state of use, availability, or unavailability (installed, serviceable, in-transit, etc.).

The fifth section provides short-term forecasts of two elements of information about the system in which we are very much interested: the number of unserviceables expected to arrive at the 5th echelon facility over the next 90 days, and the amount of serviceable spares expected to be in NICP stock 90 days from the date of the report. The rate at which unserviceables arrive at the overhaul facility is <u>on the average</u> equal to the rate of removals

TRACKING OF AVERAGE HOURS FLOWN PER AIRCRAFT
PER MONTH BY EXPONENTIAL SMOOTHING
($\alpha = 0.25$)

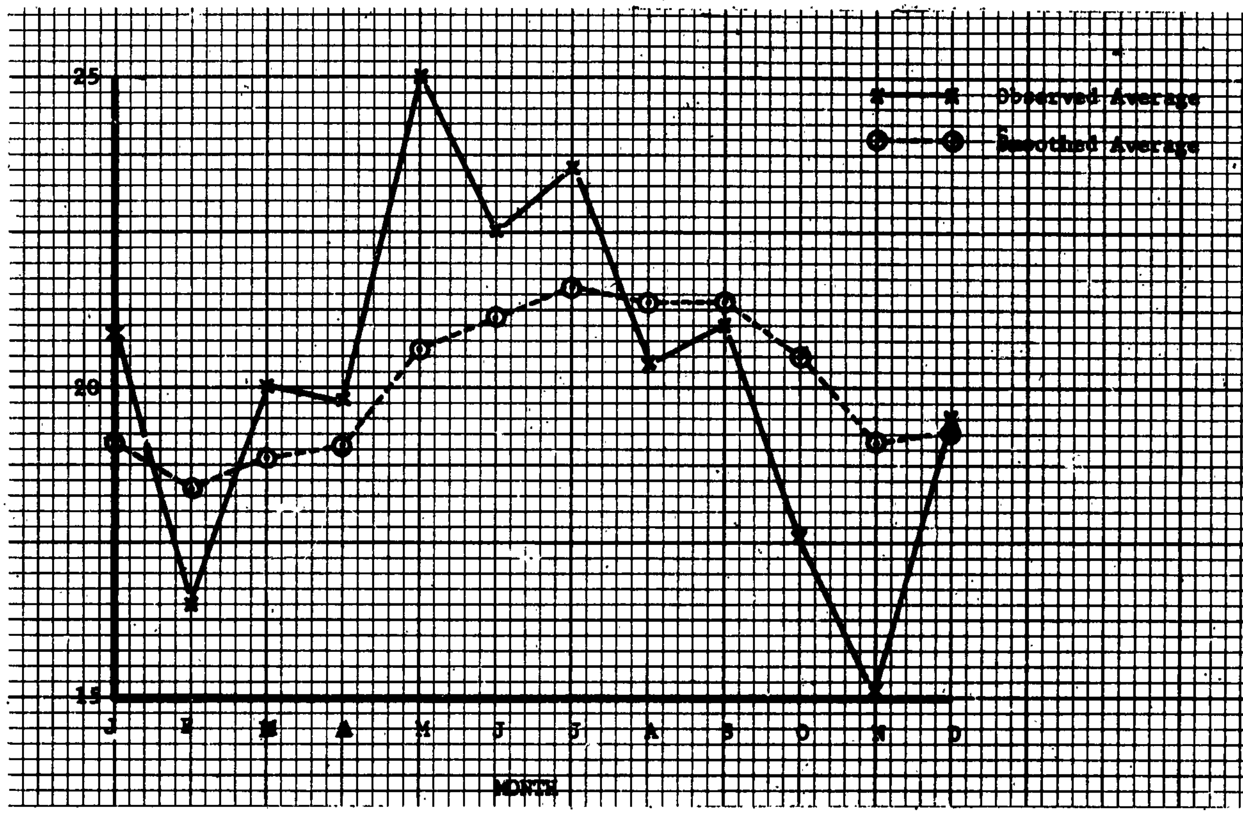

Figure 6.34

for overhaul. However, the contents of the pipeline through which unserviceables are shipped back shows substantial fluctuations from one month to the next. If the pipeline contains an abnormally high number of items, supposedly the result of a rash of removals, a higher number of unserviceables is expected to arrive at some time in the future. Conversely, if the pipeline is relatively empty, fewer unserviceables are expected to arrive. This principle is used in forecasting the arrival of unserviceables for overhaul over the next three months. The forecast equals:

1. The forecasted number of removals for overhaul over three months,

plus 2. the number of items currently in the pipeline,

minus 3. the number of items which are in the pipeline on the average.

Accordingly, the amount of serviceables on hand (NICP) three months from now is forecasted as:

1. the amount of serviceables now on hand (NICP) minus backorders,

plus 2. the number of items currently in the unserviceables pipeline and in overhaul or CONUS depot repair,

minus 3. the number of items in the pipeline and in overhaul/repair on the average.

These two figures serve as barometers of the status of the system in the short-term and are quick indicators of imbalances that need correction.

6.4.3 A NUMERICAL EXAMPLE

The Monthly Review format shown in Exhibit III has been filled out to show how the completed report should look. The data are hypothetical. Where appropriate, however, values computed in the numerical example of the Supply Control Study (see Section 6.3.2 and Exhibit I) have been carried forward to this report. The example illustrates the kinds of short-term imbalances that can be expected when the number of available spares, removal rates and pipeline times are similar to those given in the sample Supply Control Study.

Section 1. Program Factors: The number of aircraft deployed in each area as of October 1964 is shown along with a forecast of the deployment as it is expected to be at the end of the current fiscal year. In this example, the total number of aircraft deployed remains unchanged but an expected shift of 30 aircraft from 3rd Army to Viet Nam is indicated.

The Flying Hours information shows how the hours flown per aircraft in a given month can be expected to deviate from the current average value and from the forecasted value.

The TBO values shown indicate that some 3rd Army activities are using a TBO value greater than the mandatory 800 hours and that some Viet Nam activities are using something less than the mandatory 800 hours. The Regional Aircraft Logistics Managers in these areas ought to be contacted to find out what is going on.

The actual Average Wait values are compared to the theoretical values computed under the World-Wide Inventory Model. It should be remembered that the average wait can be improved by management action, such as expediting, authorizing overtime work, where the World-Wide Model does not take these special actions into account.

Section 2. Removal, Repair and Overhaul Data: Forecasts for the current fiscal year have been carried forward from the Supply Control Study. Last month and (fiscal) year-to-date values are also shown, along with the exponentially-smoothed values of the annual rates. The hypothetical data shown in this example indicate the possibility of trouble in Viet Nam where the number of removals to date appears to be too high considering that the 30 additional aircraft to be transferred to that area have not yet arrived.

Section 3. Pipeline Time Data: The sample data show a system that is not sufficiently controlled in so far as the unserviceable pipelines are concerned. Times awaiting evacuation in the overseas areas, unserviceable shipping times from overseas, areas to CONUS, times awaiting start of repair or overhaul, and 5th echelon repair and overhaul times are shown to be significantly higher than the standards. These data represent signals of future trouble and would, therefore, be the basis for calling on the Regional Aircraft Logistics Managers and the 5th echelon liaison personnel for trouble-shooting action.

Section 4. Inventory Status Data: This section is a conventional inventory report in which the component requirements are shown in terms of the aircraft positions to be satisfied and the assets are accounted for as to their geographic location and physical status. The authorized allocation of spares among user areas is also shown.

In this hypotetical example, it is assumed that the optimal Desired Area Inventory Levels computed in the previous Supply Control Study are being used as the authorized distribution plan and, since the number of spares currently in the system is rather low considering current values of removal rates and pipeline times, the customer-computed Requisitioning Objectives are shown as being somewhat higher than the authorized levels. Three areas are shown with unsatisfied aircraft positions: 2 are in 3rd Army, 9 are in Europe and 2 are in Alaska. Note that 3rd Army's total spares, including serviceables in transit, are still 2 below their Area Inventory Level and that dispatch of 2 additional serviceables is necessary to bring them in balance. Europe is in more critical condition since there are not enough serviceables on the way to satisfy even their immediate shortage. Expedited shipment of serviceables from NICP stock might be necessary if local repair actions are not able to correct the situation promptly.

While this has not been done in the example, this section of the Monthly Review can easily be transformed into a Financial Inventory Accounting Report by multiplying each of the inventory entries by the component's unit price.

Section 5. Forecasts for Next 90 Days: This section illustrates the use of the preceding data in the preparation of forecasts of two important measures of the system's status: the number of unserviceables expected to arrive at the 5th echelon facility over the next 90 days, and the number of serviceables expected to be in NICP stock 90 days from now. The first of these forecasts is useful for planning the 5th echelon work schedule and for indicating whether any changes need to be made in the allocation of resources at that facility. The second forecast can indicate incipient shortages of serviceable spares as a result of surges in other parts of the system.

In the example, the forecast of unserviceable arrivals at 5th echelon shows a surge in the process of development because of accumulations in the unserviceable shipment segment of the total unserviceable pipeline.

EXHIBIT I

SUPPLY CONTROL STUDY FORMAT

Exhibit I

SUPPLY CONTROL STUDY FOR HI-VALUE AIRCRAFT REPARABLES

SECTION 1 LONG TERM FORECASTS

PROGRAM DATA	THIS FY	FY+1	FY+2	FY+3	FY+4	FY+5
(1) NO. OF AIRCRAFT DEPLOYED	844	844.	929.	1009.	1080.	1080.
(2) FLYING HRS PER AIRCRAFT PER MONTH	35.5					30.
(3) SPECIAL NON-RECURRING SPARES REQTS	0	.	.	.	.	.

RELIABILITY DATA

(4) LONG TERM TBO 1200 HRS

FLYING HR INTERVAL	100	200	300	400	500	600	700	800	900	1000	1100	1200
(5) SURVIVAL PROBABILITY	.93	.86	.79	.72	.65	.58	.51	.44	.37	.30	.24	.17
(6) OVERHAUL RATIO	.50	.56	.63	.69	.75	.81	.88	.94	1.00	1.00	1.00	1.00

(7) MEAN TIME BETWEEN REMOVALS 500 HRS

(8) MEAN TIME BETWEEN OVERHAULS 700 HRS

LONG TERM DEMAND BREAKDOWN

(9) 4. CONUS AREAS WITH 40. AIRCRAFT EACH

(10) 1. CONUS AREAS WITH 400. AIRCRAFT EACH

(11) 3. OSEAS AREAS WITH 40. AIRCRAFT EACH

(12) 2. OSEAS AREAS WITH 200. AIRCRAFT EACH

LONG TERM REPAIR BREAKDOWN	CONUS REMOVALS FOR REPAIR		OSEAS REMOVALS FOR REPAIR	
PCT REPAIR DONE	CURRENT AVGE	LONG TERM EST	CURRENT AVGE	LONG TERM EST
(13) WITHIN AREAS	44	50.	16	20.
(14) AT CONUS 4TH ECH	0	0.	0	40.
(15) AT CONUS 5TH ECH	56	50.	84	40.

SUPPLY CONTROL STUDY FOR HI-VALUE AIRCRAFT REPARABLES

LONG TERM PIPELINE TIME, DAYS

			CURRENT AVGE	LONG TRM STANDARD	MODIFIED
	UNSERVICEABLES				
(16)	SHIPPING FROM	CONUS AREA TO CONUS DEPOT			
(17)		CONUS AREA TO 5TH ECH	43	30	
(18)		CONUS DEPOT TO 5TH ECH	33	20	
(19)		OSEAS AREA TO CONUS DEPOT	70	50	
(20)	REPAIR CYCLE	IN CONUS AREAS	15	15	
(21)		IN OSEAS AREAS	54	50	
(22)	REPAIR TIME	AT CONUS DEPOTS		50	
(23)		AT CONUS 5TH ECH	74	50	
(24)	OVERHAUL TIME	AT CONUS 5TH ECH	117	75	
	SERVICEABLES				
(25)	REPLENISHING	CONUS AREAS	29	20	
(26)		OSEAS AREAS	60	50	

(27) DESIRED LEVEL OF CUSTOMER SERVICE .5 DAYS AVGE WAIT

SUPPLY CONTROL STUDY FOR HI-VALUE AIRCRAFT REPARABLES

SECTION 2 NEXT YEAR FORECASTS

FOR N I C P LEVEL

NEXT YEAR REPAIR BREAKDOWN		CONUS REMOVALS FOR REPAIR		OSEAS REMOVALS FOR REPAIR	
PCT REPAIR DONE		CURRENT AVGE	NEXT YR EST	CURRENT AVGE	NEXT YR EST
(28)	WITHIN AREAS	44	.	16	.
(29)	AT CONUS 4TH ECH	0	.	0	.
(30)	AT CONUS 5TH ECH	56	.	84	.

UNSERVICEABLE PIPELINE TIMES, DAYS		CURRENT AVGE	CURRENT STANDARD	MODIFIED
(31) SHIPPING FROM CONUS 4TH TO 5TH ECH		33	30	
(32) REPAIR TIME	AT CONUS 4TH ECH		60	
(33)	AT CONUS 5TH ECH	74	60	
(34) OVERHAUL TIME	AT CONUS 5TH ECH	117	100	

Exhibit I

SUPPLY CONTROL STUDY FOR HI-VALUE AIRCRAFT REPARABLES

(35)
FOR 3RD ARMY AREA

PROGRAM DATA	CURRENT	NEXT YR
(36) NO. OF A/C DEPLOYED	403	373.
(37) FLYING HRS PER A/C MONTH	35	36.

RELIABILITY DATA

(38) TBO NEXT YEAR 800 HRS

FLYING HR INTERVAL 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800

(39) SURVIVAL PROBILITY

(40) OVERHAUL RATIO

(41) MEAN TIME BETWEEN REMOVALS	CURRENT AVGE	370 HRS	NEXT YEAR	300 HRS
(42) MEAN TIME BETWEEN OVERHAULS		560 HRS		580 HRS
PCT OF REMOVALS FOR REPAIR WHICH (43) ARE REPAIRED WITHIN AREA	CURRENT AVGE	30 PCT	NEXT YEAR	33 PCT

PIPELINE TIMES, DAYS	CURRENT	STANDARD	MODIFIED
(44) SHIP UNSERV. TO CONUS 4TH ECH			
(45) TO CONUS 5TH ECH	41	40	
(46) IN-AREA REPAIR CYCLE	14	15	
(47) REPLENISHMENT CYCLE, COMPLETE	26	30	
(48) SHIP TIME ONLY	24	26	

	CURRENT YEAR ACTUAL	CURRENT YEAR THEOR.	NEXT YEAR DESIRED
(49) AVERAGE CUSTOMER WAIT, DAYS	6.4	6.0	.5

SUPPLY CONTROL STUDY FOR HI-VALUE AIRCRAFT REPARABLES

SECTION 1. AREA INFORMATION

AREA	(1) AVGE REMOVALS/YR CURRENT	NEXT YR	(2) AVGE EVACNS/YR CURRENT	NEXT YR	(3) AVG IN PIPELINES CURRENT	NEXT YR	(4) AREA INVENTORY LEVEL CURRENT	AREA R/O	OPTIMUM	(5) AVG WAITING TIME AREA R/O	OPTIMUM
(1) 2ND ARMY		19		17		1.48			1		25.7
3RD ARMY		417		382		32.84			42		7.2
4TH ARMY		23		21		1.81			1		28.6
5TH ARMY		9		8		.70			0		42.7
6TH ARMY		15		14		1.19			1		23.7
CONUS TOTAL		483		442		38.02			45		
EUROPE		89		83		15.60			15		18.9
ALASKA		3		3		.53			0		81.2
KOREA		10		10		1.78			1		48.6
VIETNAM		345		345		51.99			58		10.3
OSEAS TOTAL		447		441		69.90			74		
GRAND TOTAL		930		883		107.92			119		11.7

SECTION 2. NICP SUMMARY

NICP DEMANDS	CURRENT	NEXT YR	LONG TERM
(2) THROUGH CONUS DEPOT REPAIR		0	43
(3) THROUGH 5TH ECH REPAIR		263	100
(4) THROUGH 5TH ECH OVERHAUL		620	556
NICP REPAIR CYCLE			
(5) AVGE DAYS IN CYCLE		153	119
(6) AVGE NUMBER IN CYCLE		370	228

SUPPLY CONTROL STUDY FOR HI-VALUE AIRCRAFT REPARABLES — OUTPUT DATA * PAGE 2

SECTION 3. PHASED INVENTORY POSITION

		CURRENT	NEXT FY	FY + 2	FY + 3	FY + 4	FY + 5
(7)	A/C INSTALLED REQTS	844					
(8)	REQUIREMENTS INCREASE		0	85	80	71	0
(9)	EXPECTED A/C ATTRITION		-	-	-	-	-
(10)	NET A/C INSTALLED REQTS	844	844	929	1009	1080	1080
(11)	TOTAL COMPONENT ASSETS	1294					
(12)	COMPONENT PROC. DUE-IN		-	-	-	-	-
(13)	EXPECTED COMP. ATTRITION		-	-	-	-	-
(14)	SPECIAL N-RECURRING REQTS		-	-	-	-	-
(15)	NET COMPONENT ASSETS	1294	1294	1379	1459	1530	1530
(16)	NET COMPONENT SPARES	450	450	450	450	450	* 450 *
(17)	LONG-TERM DESIRED INV. LVL						* 340 *

AVERAGE CUSTOMER WAIT NEXT YEAR

(18) WITH CURRENT ASSETS * 11.7 DAYS * (CURRENT YEAR ACTUAL IS 6.4 DAYS THEORETICAL 5.7 DAYS)

(19) DESIRED WAIT IS * .5 DAYS *

(20) WITH CHANGES IN SPARES LEVEL OR PIPELINE TIMES

TOTAL SPARES		AVGE WAIT
450	CURRENT	11.7
460		8.5
470		5.9
480		3.8
490		2.3
500		1.3
510		.7
515		.5

PIPELINE CHANGE	AVGE WAIT
CURRENT	11.7
- 5 PCT	5.1
- 10 PCT	1.4
- 15 PCT	.2

SUPPLY CONTROL STUDY FOR HI-VALUE AIRCRAFT REPARABLES

SECTION 4 RECOMMENDED ACTIONS FOR NEXT FY

	QUANTITY	UNIT COST	DOLLAR VALUE
(21) OVERHAULS			
(22) REPAIRS AT CONUS 5TH ECH			
(23) MODIFICATIONS			
(24) PROCUREMENT			
(25) OTHER ACTIONS			

EXHIBIT II

DESCRIPTION OF THE SUPPLY CONTROL STUDY FORMAT

EXHIBIT II

DESCRIPTION OF THE SUPPLY CONTROL STUDY FORMAT

INPUT DATA, SECTION 1: LONG-TERM FORECASTS

Line No.	Data Furnished by Computer	Modification/Inserts by Commodity Analyst
1	Total number of aircraft now deployed, not broken down by area.	Forecast of total aircraft population for each of 5 fiscal years in the future.
2	Average number of hours flown per aircraft per month, calculated from DA 1352 data.	The average number of hours flown per aircraft per month in the long-term future.
3	Special non-recurring spares requirements, (i.e., in addition to the requirements for support of operational aircraft under present conditions, such as mobilization reserves, MAP requirements, etc.). The computer maintains in its master files a record of these requirements.	Forecast of non-recurring requirements by fiscal year for 5 years in the future.
4-8	The smoothed Survival Probability and Overhaul Ratio Curves, long-term TBO and MTBR/ MTBO values are printed out by the computer for the Commodity Analyst's information. These values represent the final results of Step I.	None.
9-12	None.	To be furnished by the Commodity Analyst; representing his best judgement of how the aircraft population will be distributed between CONUS and overseas in the long-term. Two (2) lines are provided for each so that the analyst may distinguish between areas of heavy and

INPUT DATA, SECTION 1: LONG-TERM FORECASTS (continued)

Line No.	Data Furnished by Computer	Modification/Inserts by Commodity Analyst
		light activity. See Exhibit I for an example.
13-15	The computer print-out is calculated from DA 2410 data. All removals that have resulted in repair (as opposed to overhaul) are tabulated to determine the fraction that were repaired within the areas, at CONUS 4th echelon activities and at CONUS 5th echelon. This is done separately for removals originating overseas and for those originating in CONUS.	The Commodity Analyst may enter modifications of the current averages if changes in repair policies are expected (e.g., more repair to be done overseas than is done currently). If no entries are made the computations in Step III will be based on the current averages.
16-26	The computer print-outs current average pipeline times, computed from continuous processing of DA 2410 data. It also shows the standards that are set for the long-term.	Agreed upon modifications to the long-term standard pipeline times may be entered here. In the absence of a modification, the computer uses the standard already in the master file.
27	None.	The long-term Desired Level of Customer Service (expressed in average days of wait) is presumably set as a matter of policy at the time of the Supply Control Studies.

INPUT DATA, SECTION 2: NEXT FISCAL YEAR FORECASTS

The data in this section are essentially of the same type as described in Section 1, except that they represent expectations of system parameters for the next fiscal year, rather than for the long-term. Since more detailed information is needed in planning for the next fiscal year's level of activity, forecasts must be made separately for each of the geographical areas.

Line No.	Data Furnished by Computer	Modification/Inserts by Commodity Analyst
28-30	Same as lines 13-15.	Same as lines 13-15, but for next fiscal year.
31-34	Average NICP pipeline times are calculated by the computer from the DA 2410 data. The computer also prints for reference the standard pipeline times.	The analyst may recommend changes in the standards for the next fiscal year. Modified values are entered in the space provided if such recommendations are approved.

Lines 35-49 refer to the input data for a particular area. Every area will be represented by a separate page according to this format. The number of areas is variable, depending on the dispersion of the aircraft. The information contained in these sections is outlined in the following:

35	Identification of the area concerned.	None.
36,37	Number of aircraft deployed in the area and the average flying hours per aircraft per year computed from DA 1352 data for the particular area.	Projected aircraft deployment and flying hours forecast for the next fiscal year.

INPUT DATA, SECTION 2: NEXT FISCAL YEAR FORECASTS (continued)

Line No.	Data Furnished by Computer	Modification/Inserts by Commodity Analyst
38-42	The official TBO value for next year, the smoothed Survival Probability and Overhaul Ratio Curves for next year, and MTBR/MTBC's values, current and next year, are printed out for the Analyst's information. These are projected by the Aviation Components Life Committee by area.	None.
43	The fraction of all removals for repair which were repaired within the area itself, computed from DA 2410 transactions.	The Analyst may modify this figure if changes in repair policies are expected in the next fiscal year. If not this space is left blank and the computer uses the current value for subsequent calculations.
44-48	These are the pipeline times for the particular area. Current values are calculated from DA 2410 data and printed along with the standards applicable.	Modified values, if approved, are entered here.
49	The actual Average Customer Wait (in days), which is the measure of performance used in this system, is calculated from DA 2410 data for the particular area. The theoretical average customer wait, computed at the time of the previous supply control study for the current year, is printed out for comparison.	Next year's desired average wait for the area. The Commodity Analyst, by modification of this desired average wait, can, in effect, change the military essentiality rating of the area relative to the other areas. A greater proportion of the available system assets is assigned to those areas where the least customer wait is desired.

OUTPUT DATA - SECTION 1: AREA INFORMATION

Column No.	
1,2	Average Removal and Evacuation Rates: Current average values are calculated from DA 2410 data. The next fiscal year value is a forecast calculated either by the actuarial method or by dividing the projected number of flying hours by MTBR/MTBO, taking into account the fraction that will be repaired locally.
3	Average Number of Items in Area Pipelines: This is the sum of items in the local repair cycle, and in the replenishment cycle (which consists of the delay in transmission of a DA 2410 or DA 2410-1 signifying evacuation of an unserviceable item from the area, the processing of the serviceable dispatch action and the physical shipment of a serviceable replacement to the area inventory pool).
4	Area Inventory Level: This is the authorized inventory level for the area covering its local repair cycle, replenishment cycle and stock on hand. The current value is the level authorized at the time the study is done. The Area Requisitioning Objectives are furnished by the areas to the NICP. The optimal value is calculated on the basis of next fiscal year's removals, pipeline times, spares assets and desired customer wait. The optimal levels are calculated for all areas simultaneously and represent the levels that will result in minimum customer wait over-all.
5	Average Waiting Time: This is the time a removing organization has to wait, on the average, to obtain a serviceable replacement for a particular aircraft because of unavailability of the item in the area. Times when the customer does not wait (i.e., when a serviceable replacement is immediately available) are considered in this calculation. Two values are shown, first the average wait which would result from using the Area Requisitioning Objectives and, secondly, the average wait which would result from using the optimal Inventory Levels.

OUTPUT DATA -- SECTION 2: THE NICP SUMMARY

Line No.	
2-4	NICP Demands: These three (3) lines represent evacuations from the areas for which serviceable replacements are required, indicating at which echelon they are finally repaired or overhauled.
5,6	NICP Repair Cycle: Includes all items from the time they are evacuated from an area until they are restored to serviceable condition (within-area repair actions are excluded). Both the average duration of this repair cycle in days and the average contents of this pipeline are given.

OUTPUT DATA - SECTION 3: PHASED INVENTORY POSITION

Line No.	
7	Aircraft Installed Requirements: The current number of aircraft positions; e.g., 100 two-engine aircraft will have an installed requirement of 200 engines.
8	Requirements Increase: Each column shows the additional requirements that are programmed for entry into the system during the year.
9	Expected Aircraft Attrition: A standard aircraft attrition rate, expressed as a percentage of the aircraft population will be developed from past experience and retained in the computer master file. This line merely shows the application of this rate to the programmed Aircraft Installed Requirements (equals current Installed Requirements plus planned increases to date).
10	Net Aircraft Installed Requirements: Equals programmed Aircraft Installed Requirements minus Expected Aircraft Attrition.
11	Total Component Assets: The total quantity of the components now available in the system; including installed and uninstalled, serviceable and unserviceable items.
12	Component Procurement Due-In: Self-explanatory.
13	Expected Component Attrition: Similar to the aircraft attrition (line no. 12), except it applies to the component itself. It includes not only components lost through crash damage, etc., but also those that are washed out as not reparable during repair or overhaul. A standard attrition factor, based on past experience, is stored in the computer master file for this purpose.
14	Special Non-Recurring Requirements: Re-statement of the data supplied by the analyst in Line 3 of the Input.

OUTPUT DATA -- SECTION 2: THE NICP SUMMARY

Line No.	
2-4	NICP Demands: These three (3) lines represent evacuations from the areas for which serviceable replacements are required, indicating at which echelon they are finally repaired or overhauled.
5,6	NICP Repair Cycle: Includes all items from the time they are evacuated from an area until they are restored to serviceable condition (within-area repair actions are excluded). Both the average duration of this repair cycle in days and the average contents of this pipeline are given.

OUTPUT DATA - SECTION 3: PHASED INVENTORY POSITION (continued)

Line No.	
15	Net Component Assets: Equals current Total Component Assets plus Requirements Increases to date plus Procurement Due-Ins to date minus Expected Component Attrition to date minus Special Non-Recurring Requirements to date.
16	Net Component Spares: Equals Net Component Assets minus Net Aircraft Installed Requirements. The results represent the number of spares available for filling the pipeline and for serving as safety stock.
17	Long-Term Desired Inventory Level: This figure is calculated to achieve the long-term Desired Level of Customer Service based on rates and pipeline times projected for five years from now. The principal comparison is with the Net Component Spares projected for five years into the future.
18,19	Average Customer Wait with Current Assets: The first figure represents the computed average wait for all customers based on the projections of rates, pipeline times and spares level for the next fiscal year; it is obtained by combining the optimal average waiting times for the individual areas (right-hand side of Column 5, Section 1 of the Output). The second figure reflects the combined value of the next year's desired waiting times for the different areas (third entry, line 49 of the Input). The current year figures, actual and theoretical, are given for purposes of comparison. They correspond directly to the consolidated averages of the current year by area figures on line 49 of the Input Data.
20	Average Customer Wait with Changes in Spares Level or Pipeline Times: The value of Average Customer Wait that can theoretically be achieved next year may not be satisfactory. This section will provide the Analyst with additional information on what it would take to improve the situation, either in additional spares or in shorter pipelines. The number of printed lines will not always be the same but depends somewhat on the particular situation encountered. In any case, the bottom line indicates the number of spares required during the next year to achieve the desired customer wait or better, keeping pipeline times unchanged (first two columns), and the percentage speed-up in all pipelines which is required to bring about the same effect but keeping the number of spares equal to what it currently is (last two columns).

OUTPUT DATA - SECTION 4: RECOMMENDED ACTIONS FOR NEXT FISCAL YEAR

The entries in this section are self-explanatory with two possible exceptions:

Line No.

24 Modifications: This space is provided in case assets of a different Model or Series of a component exist which can be converted to a more desirable configuration by a modification program.

26 Other Actions: The Analyst may enter here recommendations involving changes in TBC, changes in the mode of transportation to be used in particular segments of the pipeline, etc.

EXHIBIT III

MONTHLY REVIEW FORMAT

MANAGEMENT SYSTEM FOR HI VALUE AIRCRAFT REPARABLES

MONTHLY REVIEW OCTOBER 1964

SECTION 1 PROGRAM FACTORS

AREAS	(1) A/C DEPLOYMENT		(2) FLYING HOURS			(3) T B O		(4) AVERAGE WAIT	
	ACTUAL	FORECAST	LAST MONTH	AVG/MO	FORECST/MO	LAST MONTH	STANDARD	ACTUAL	FORECAST
2ND ARMY	28	28	19.0	20.0	22.0	800	800	6.0	8.4
3RD ARMY	403	373	27.0	35.0	36.0	846	800	6.4	6.0
4TH ARMY	24	24	31.0	32.0	30.0	800	800	9.4	8.8
5TH ARMY	17	17	15.0	14.0	16.0	800	800	13.5	11.2
6TH ARMY	22	22	16.0	24.0	22.0	800	800	9.1	7.6
TOTAL CONUS	494	464	25.4	32.8	33.4			6.8	6.4
EUROPE	118	118	21.0	26.0	24.0	800	800	7.6	5.9
VIETNAM	207	237	56.0	52.0	47.0	727	800	5.1	4.7
KOREA	15	15	24.0	22.0	22.0	800	800	8.4	9.2
ALASKA	10	10	8.0	12.0	12.0	800	800	17.7	16.4
TOTAL OSEAS	350	380	41.5	40.8	38.0			5.9	5.2
GRAND TOTAL	844	844	32.3	36.1	35.5			6.4	5.7

Exhibit III

MANAGEMENT SYSTEM FOR HI-VALUE AIRCRAFT REPARABLES

MONTHLY REVIEW OCTOBER 1964

SECTION 2 REMOVAL REPAIR AND OVERHAUL DATA

AREAS	(1) REMOVALS				(2) EVACS TO CONUS 4TH				(3) EVACS TO CONUS 5TH				(4) REPAIRS				(5) OVERHAULS			
	THIS MO	FY/T DATE	AVG /YR	FY FCST	THIS MO	FY/T DATE	AVG /YR	FY FCST	THIS MO	FY/T DATE	AVG /YR	FY FCST	THIS MO	FY/T DATE	AVG /YR	FY FCST	THIS MO	FY/T DATE	AVG /YR	FY FCST
2ND ARMY	1	6	23	19					1	5	20	17	1	1	3	2				
3RD ARMY	37	128	496	417					32	116	420	382	5	12	76	35				
4TH ARMY	3	6	17	23					3	6	15	21	0	0	2	2				
5TH ARMY	0	1	12	9					0	1	10	8	0	0	2	1				
6TH ARMY	2	4	15	23					2	4	15	14	0	0	8	1				
TOTAL CONUS	43	145	563	491					38	132	480	442	6	13	91	41				
EUROPE	12	34	114	89	11	33	100	83					1	1	14	6				
VIETNAM	41	129	302	345	41	129	302	345												
KOREA	0	2	12	10	0	2	12	10												
ALASKA	0	0	2	3	0	0	2	3												
TOTAL OSEAS	53	165	430	447	52	164	416	441					1	1	14	6				
ATLANTA									4	15	49	32	-	-	-	-				
FT WORTH									10	42	151	144	-	-	-	-				
N.CMBRLND									7	12	50	51	-	5	5	-				
SHARPE									25	61	170	214	-	-	-	-				
ARADMAC													22	81	230	263	48	159	594	620
GRAND TOTAL	96	310	993	938	52	164	416	441	84	282	900	883	29	100	340	310	48	159	594	620

Exhibit III

MANAGEMENT SYSTEM FOR HI-VALUE AIRCRAFT REPARABLES

MONTHLY REVIEW OCTOBER 1964

SECTION 3 PIPELINE TIME DATA

AREAS	(1) REPLENISHMT CYCLE		(2) SERVICEABLE SHIP TIME		(3) UNSERVICE AWAITING EVACUATION		(4) UNSERVICE SHIP TO CONUS 4TH		(5) UNSERVICE SHIP TO CONUS 5TH		(6) AWAITING REPAIR / OVERHAUL		(7) REPAIR TIME		(8) OVERHAUL TIME	
	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD	AVG	STD
2ND ARMY	31	30	28	26	11	3			44	40			12	15		
3RD ARMY	26	30	24	26	5	3			41	40			14	15		
4TH ARMY	25	30	21	26	6	3			32	40			15	15		
5TH ARMY	35	30	33	26	9	3			49	40			18	15		
6TH ARMY	41	30	38	26	6	3			41	40			14	15		
CONUS AVGE	27	30	25	26	5	3			41	40			14	15		
EUROPE	63	65	58	60	11	3	64	60					54	50		
VIETNAM	57	55	52	50	8	3	72	60								
KOREA	68	65	64	60	16	3	63	60								
ALASKA	71	65	65	60	4	3	58	60								
OSEAS AVGE	59	58	55	53	9	2	70	60								
ATLANTA									-	30						
FT WORTH									-	30						
N.CMBRLND									32	30						
SHARPE									34	30						
ARADMAC											13	5	61	55	104	95

TOTAL UNSERVICEABLE CYCLE TIME (NICP)
AVGE 183 DAYS STANDARD 153 DAYS

Exhibit III

MANAGEMENT SYSTEM FOR HI VALUE AIRCRAFT REPARABLES

MONTHLY REVIEW OCTOBER 1964

SECTION 4 INVENTORY STATUS DATA

AREAS	(1) AIRCRAFT POSITIONS	(2) INST SERVIC	(3) UNINST SERVIC	(4) PROCUREMT DUE IN	(5) AREA BCKORDRS	(6) ON HND UNSERV	(7) SERVIC IN TRANSIT TO AREAS	(8) IN REPAIR O/HAUL	(9) UNSERV IN TRANSIT FROM AREAS	(10) TOTAL SPARES	(11) AREA R/O	(12) INV LEVEL AUTHORZD
2ND ARMY	28	28	1		-	-	-	-	-	1	2	1
3RD ARMY	373	371	-		2	12	20	10	28	40	45	42
4TH ARMY	24	24	1		-	-	-	-	-	1	2	1
5TH ARMY	17	17	-		-	-	-	-	-	-	1	0
6TH ARMY	22	22	1		-	-	-	-	-	1	2	1
TOTAL CONUS	464	462	3		2	12	20	10	28	43	52	45
EUROPE	118	109	-		9	4	8	9	21	12	21	15
VIETNAM	237	237	21		-	12	24	-	56	58	58	57
KOREA	15	15	1		-	-	-	-	-	1	2	1
ALASKA	10	8	-		2	1	2	-	-	1	1	1
TOTAL OSEAS	380	369	22		11	18	34	9	77	72	82	74
AREAS TOTAL	844	831	25		13	30	54	19	105	115	134	119
ATLANTA												
FT WORTH												
N CMBRLND			4			20						
SHARPE			11			48						
ARADMAC								147	105			
NICP TOTAL			15	0		68		147	105	335		
GRAND TOTAL			40	0	13	98	54	166	105	450		

MANAGEMENT SYSTEM FOR HI-VALUE AIRCRAFT REPARABLES

MONTHLY REVIEW OCTOBER 1964

SECTION 5 FORECASTS FOR NEXT 90 DAYS

1.FORECAST OF UNSERVICEABLE RETURNS TO 5TH ECHELON	A + B - C
A.EXPECTED REMOVALS FOR EVAC TO 5TH ECHELON	218
B.NUMBER NOW IN NICP UNSERV. SHIP PIPELINE	243
C.AVGE NUMBER IN NICP UNSERV. SHIP PIPELINE	198
FORECAST	263
2.FORECAST OF SERVICEABLE NICP INVENTORY 90 DAYS FROM NOW	A - B + C - D
A.NUMBER OF SERVICEABLES NOW ON HAND AT NICP	15
B.NUMBER OF AREA BACKORDERS	13
C.NUMBER NOW IN NICP TOTAL UNSERV. PIPELINE	390
D.AVGE NUMBER IN NICP TOTAL UNSERV. PIPELINE	368
FORECAST	24

EXHIBIT IV

DESCRIPTION OF THE MONTHLY REVIEW FORMAT

DESCRIPTION OF THE MONTHLY REVIEW FORMAT

SECTION 1 - PROGRAM FACTORS

Column

1 Aircraft Deployment: depicts how many aircraft are now deployed in each user area and how many are expected to be deployed by the end of the current fiscal year. The forecast figure comes from the Supply Control Study. DA 1352's provide the input for the actual figures.

2 Flying Hours: the actual hours flown per aircraft last month are shown for each area, along with the exponentially smoothed averages and the forecast for the current fiscal year. The latter is obtained from the Supply Control Study. The last month and smoothed average figures are calculated from DA 1352 data.

3 Time-Between-Overhaul: data are extracted from DA 2410 removal transactions to compute the average of the TBO's reported in each area. Any deviation from the prescribed TBO can thus be traced.

4 Average Wait: the forecast comes from the Supply Control Study calculation using the World-Wide Inventory Model. The actual wait is calculated by observing the elapsed time between component removal and installation of a serviceable on the aircraft; it is an exponentially-smoothed average.

SECTION 2 - REMOVAL, REPAIR AND OVERHAUL DATA

Each column shows the activity that occurred during the past month, the cumulative activity to this point of the fiscal year, the exponentially-smoothed average rate of activity and the forecast of the volume of activity expected for the complete fiscal year. The forecast rates are obtained from previous Supply Control Study calculations. The balance of the entries come from processing of the 2410 and 2410-1 data. Column headings are self-explanatory.

SECTION 3 - PIPELINE TIME DATA

This section compares exponentially-smoothed averages of the observed cycle time segments with standard values. Observed pipeline times are calculated from 2410 and 2410-1 data. Averages are computed by giving more or less weight to the current month's average depending upon the number of observations, as has been described in Section 6.4.1.

Column

1 Replenishment Cycle: this is the time that elapses from removal of an unserviceable from an aircraft until the serviceable replacement from the NICP arrives in the area. This includes the time required for preparation of the 2410 transaction, transmission of the transaction to AVCOM, processing the shipping transaction and physical shipping time of the serviceable replacement to the area.

2 Serviceable Shipping Time: this is the portion of the Replenishment Cycle time consumed in the physical shipment of the serviceable replacement from NICP stock to the user area.

3 Unserviceable Awaiting Evacuation: this is the time that a removed unserviceable component waits in the user area until it is shipped out of the area for repair or overhaul. Items that are locally repaired in the area and not evacuated are not counted here; their waiting time is included in the area Repair Time (Column 7).

4 Unserviceable Shipping Time to CONUS 4th Echelon: this pipeline segment is included to track those cases when Overseas areas ship their unserviceables to CONUS depos rather than directly to a 5th echelon facility.

5 Unserviceable Shipping Time to CONUS 5th Echelon: self-explanatory.

SECTION 3 - PIPELINE TIME DATA (continued)

Column

6 — Time Awaiting Repair or Overhaul: this column is used only for NICP level (4th and 5th echelon) repair and overhaul. This is the time that elapses between receipt of the unserviceable at the repair/overhaul facility and the start of the physical repair action. In the case of repair actions in the local areas, their time awaiting repair is included in the total Repair Time in Column (7).

7 — Repair Time: In the case of a geographical area, this is the average time to repair a component locally (i.e. not involving NICP intervention) counting from the removal of the component until it has been returned to the area's serviceable stock. This has been called the local repair cycle time elsewhere. In the case of a CONUS depot or CONUS 5th Echelon facility, however, these entries are interpreted as the time from start of repair or overhaul until completion.

8 — Overhaul Time: this refers only to CONUS depots and 5th Echelon facilities. The interpretation is similar to that of Repair Time.

Total Unserviceable Cycle Time (NICP): this is the weighted average sum of Columns 4, 5, 6, 7 (CONUS depots and 5th Echelon only), and 8. The weight is the fraction of all transactions that pass through the particular pipeline segment being tracked.

SECTION 4 - INVENTORY STATUS DATA

This section is self-explanatory, if the following relationships are noted:

Column	
5	Column (5) = Column (1) - Column (2)
10	Column (10) for the areas = Column (3) + Column (6) + Column (7) + Column (8) - Column (5)
	Column (10) for the NICP = Column (3) + Column (4) + Column (6) + Column (8) + Column (9) for the 4th and 5th echelon activities.
	Column (10) grand total = Column (3) + Column (4) + Column (6) + Column (7) + Column (8) + Column (9) - Column (5).
11	Entries in this column reflect the Requisitioning Objectives for each of the using areas as reported to AVCOM. These RO's are shown to provide a comparison with the authorized Area Inventory Levels.
12	These entries are the authorized Area Inventory Levels as of the previous Supply Control Study.

SECTION 5 - FORECASTS FOR NEXT 90 DAYS

This section compares the current contents of the pipelines of interest to their smoothed average contents. The difference represents surges, either positive or negative, that can be expected to lead to imbalances over the next 90 days. The calculations are self-explanatory.

APPENDIX A

ASSISTANT SECRETARY OF DEFENSE
Washington 25, D. C.

Installations and Logistics August 17, 1962

MEMORANDUM FOR THE ASSISTANT SECRETARY OF THE ARMY (I&L)
THE ASSISTANT SECRETARY OF THE NAVY (I&L)
THE ASSISTANT SECRETARY OF THE AIR FORCE (MAT)
THE DIRECTOR, DEFENSE SUPPLY AGENCY

SUBJECT: Aviation Materiel Management Improvement Program

The management of aviation materiel has been the object of increasing analysis and review by the Congress and the Comptroller General. Lack of Congressional confidence was evident during the hearings held in March, 1962 by the House Subcommittee on Department of Defense Appropriations. Criticisms cited at that time were that knowledge and control of assets were inadequate; requirement computation and materiel management techniques were faulty; and interservicing of assets and data were unsatisfactory. An immediate result was the House's initial action to reduce Air Force and Navy aviation spares funding requests for FY 1963 by \$85 million and \$45 million, respectively.

Aviation materiel, with \$27.5 billion installed and \$11.8 billion in the supply system, accounts for close to a \$40 billion inventory; almost one-third of the total DoD world-wide personal property inventory. The military and financial importance of the aviation spares commodity area and the inherent complexity of its management have for some time been the stimulus for our respective staffs to identify management weaknesses and develop improvements. While many improvements have been installed, much more needs to be done. The importance of this management area prohibits any business-as-usual approach.

To exploit the best of the various management practices of the Military Departments and to optimize collective action among them, it is particularly important that major improvement actions be consistent within and between Military Departments. Proceeding on an interrelated basis throughout the Department of Defense is essential. Instances in which we may have overlooked opportunities to work together have been spotlighted as the source of ineffective use of resources and have been a principal cause of dissatisfaction with aviation spares management both within and among the Military Departments.

A task group, which included Departmental representatives on an informal basis, has developed an action plan for an Aviation Materiel Management Improvement Program to be carried out jointly by my staff and the Military Departments. This program delineates management improvement actions required for aviation spares in six major problem areas, three commodity groupings and three functional activities, as follows: reparable items (excluding engines), aircraft engines, non-reparable items, financial management, and interservicing of assets and technical data. For each of these, specific management improvement actions are planned, as appropriate, at the operating base or station level, in the depot or commercial contractor repair cycle segment and for the system (inventory control point) level.

The past participation of the Military Departments, through their representation in the task group and their facilitating its activities, has been a valuable factor in creating this improvement plan. Recent Departmental actions to tighten control of aviation spares requirements and assets are in the right direction. Putting the Aviation Materiel Management Improvement Program into operation, obtaining a sound interrelated advance across all Departments and assuring rapid progress all demand continued Military Department participation. Each of the Departments has already been contacted with respect to placing an officer in the Office of the Assistant Secretary of Defense (Installations and Logistics) to assist in this program and two of the representatives have already been assigned. One of the first tasks of this group will be to develop specific milestones as aids in guiding the Military Departments in this work and in obtaining and assessing reports of progress. Their continuing duties will be to prosecute the implementation of the Aviation Materiel Management Improvement Program by detailing further its phased accomplishment, working closely with the Military Departments in the execution of the plan, expediting and judging progress, and undertaking additional fact-finding and analysis in areas requiring further study.

There has been sentiment for integrated management in the aviation spares area; recommendations of the Comptroller General along this line in connection with the utilization of aircraft engines and the reclamation of spare parts from excess engines are examples. The highly technical aspects of aviation spares, their intimate tie to weapon systems, and the widely differing management concepts and practices of the Military Departments all suggest that the type of management improvement and increased commonality of Military Department approaches we are seeking in this program should precede any serious integration considerations. Subsequently, integrated management may be found to be feasible and facilitated, particularly for the lower price, more common use, non-reparable items. To this end the Defense Supply Agency which is completing its pilot study in the aviation spares management area should also assign a representative to work full time on this program with the Installations and Logistics staff.

It is essential that we secure major improvements in the management of aviation materiel. Accomplishing the Aviation Materiel Management Improvement Program in FY 1963 and FY 1964 is a prerequisite.

/s/Thomas D. Morris
Thomas D. Morris
Assistant Secretary of Defense
(Installations and Logistics)

1 Inclosure

APPENDIX B

THE ACTUARIAL FORECASTING TECHNIQUE

DESCRIPTION OF THE MODEL

The actuarial approach provides a framework for describing the current reliability characteristics of an item and for estimating future requirements of replacement items. The life span of an item, measured in flying hours, is divided into a number of age intervals. For instance, if a particular model engine has a TBO of 500 flying hours, we might use 5 intervals of 100 hours each. With each interval is associated a failure rate. The actuarial failure rate in a particular interval represents the probability that a component, if subjected to use within the interval starting at its beginning, will fail before reaching the end of the interval. For example, a failure rate in the interval 100-200 hours of .20 means that of all components which pass the 100 hours point in serviceable condition, on the average 20% will fail before reaching 200 hours. Two different sets of failure rates are required in cases where some of the unserviceables are repaired rather than overhauled; one set describing the probability of a removal resulting in overhaul for each interval, and the other set describing the probabilities of removal regardless of whether it results in repair or overhaul.

These two sets of failure rates uniquely define the failure characteristics of a component. However, in analyzing historical failure data and projecting failures into the future we will mostly use quantities which

NUMERICAL EXAMPLE

Interval	From-To	Failure Rate All Removals	Failure Rate O'haul Only	Percent Surviving Start of Interval	Percent Failing: O'haul Only Interv.	O'haul Only Cumul.	All Removals Interv.	All Removals Cumul.	Repair All Interv.	Repair All Cumul.
i		f_i	f'_i	S_{i-1}	x_i	X_i	y_i	Y_i	z_i	Z_i
1	0-100	.50	.10	100	10	10	50	50	50	50
2	100-200	.50	.20	90	18	28	45	95	50	100
3	200-300	.50	.30	72	21.6	49.6	36	131	50	150
4	300-400	.50	.40	50.4	20.16	69.76	25.2	156.2	50	200
5	400-500	.50	.50	30.24	15.12	84.88	15.12	171.3	50	250
At TBO = 500 hrs.		1.00	1.00	15.12	15.12	100	15.12	186.42	100	350

are derived from the actuarial failure rates such as survival probabilities, overhaul ratios, mean-time-between-overhauls, mean-time-between-removals, rather than actuarial failure rates themselves, because this is conceptually advantageous. The example on the opposite page serves to illustrate the relationships between the different quantities in use.

In the first interval (0-100 hours) the failure rate for all removals is $f_1 = .50$, which means that a fraction $y_1 = 50\%$ is expected to fail before reaching 100 hours. However, the failure rate for overhauls, f_1' is .10 and thus only one out of every five failures in this interval is overhauled (the overhaul ration $r_1 = .1/.5=.2$); the other four are repaired and will continue on to riper age. The fraction failing for overhaul, $x_1 = 10\%$, meaning that at the end of the first interval only 90% of the items starting at zero hours are still "alive."

In the second interval (100-200 hours), the failure rate for all removals, f_2, is again equal to .50, but since only 90% of all items reach 100 hours, the number of items which will fail between 100 and 200 hours is necessarily smaller than the number which fails between 0 and 100 hours; expressed as a percentage of the number of items starting at zero hours we find that it equals 45% ($y_2 = .50 \times 90\%$). Notice that of the failures that take place between 100 and 200 hours, a greater fraction, namely 40% ($r_2 = .20/.50$) is overhauled; 18%($x_2 = .20 \times 90\%$) of the items fall victim to overhaul between 100 and 200 hours, so that only 72% of the items ($S_2 = 90 - 18$) reach 200 hours.

In the third interval:

$$y_3 = f_3 \cdot S_2 \quad = .50 \times 72 = 36\%$$

$$x_3 = f_3' \cdot S_2 \quad = .30 \times 72 = 21.6\%$$

$$S_3 = S_2 - x_3 \quad = 72 - 21.6 = 50.4\%$$

$$r_3 = f_3'/f_3 \quad = .30/.50 = .60$$

Continuing in this fashion through the 4th and 5th intervals we find that only 15.12% of all items reaches the TBO of 500 hours, despite the heavy repair action which takes place in the case of items which have logged only a small number of hours. The x_i column shows at which ages removals for overhaul occur:

10%	fail between	0 and	100 hours	;	average age	50	hours
18%	"	" 100 "	200 "	;	"	" 150	"
21.6 %	"	" 200 "	300 "	;	"	" 250	"
20.16%	"	" 300 "	400 "	;	"	" 350	"
15.12%	"	" 400 "	500 "	;	"	" 450	"
15.12%	fail at the TBO of		500 hours	;	"	" 500	"

Weighing these average ages by the applicable percentages we find that the overall average age at overhaul (or Mean-Time-Between-Overhauls) is:

$$.10 \times 50 + .18 \times 150 + .216 \times 250 + .2016 \times 350 + .1512 \times 450 + .1512 \times 500$$
$$= 300.2 \text{ hours}$$

Another way of computing the MTBO is by summing up the survival probabilities (counting S_0 and S_5 for only one-half) and multiplying by the length of one interval, T:

$$MTBO = T\ (1/2\ S_0 + S_1 + S_2 + S_3 + S_4 + 1/2\ S_5)$$

$$= 100\ (.50 + .90 + .72 + .504 + .3024 + .0756) = 300.2 \text{ hours}$$

The y_i column compared with the x_i column relates the frequency of removals to the frequency of overhauls. The total of all y_i's equals 186.42, so that the average item undergoes 1.8642, or almost 2, removals for every overhaul. The Mean-Time-Between-Removals is therefore equal to 300.2 divided by 1.8642, or about 161 hours.

The surviving fraction S_i and the failing fractions x_i and y_i really show the composite effect of item reliability and repair policy (i.e., concerning the overhaul versus repair decision). For the same item with identical reliability we get an entirely different result if either a greater, or a smaller proportion of the removals is repaired rather than overhauled. The two effects can be separated by constructing a hypothetical history under the assumption that all removals will be repaired and that overhaul can in all cases be postponed to the TBO. This hypothetical case, characterized by the failing fractions z_i, enables one to focus on the reliability of the item without clouding the picture with the effects of repair policy (which is completely defined by means of the overhaul ratios r_i). The surviving fraction is always equal to one since no overhaul takes place within the TBO; the failing fraction z_i therefore equals the actuarial failure rate f_i.

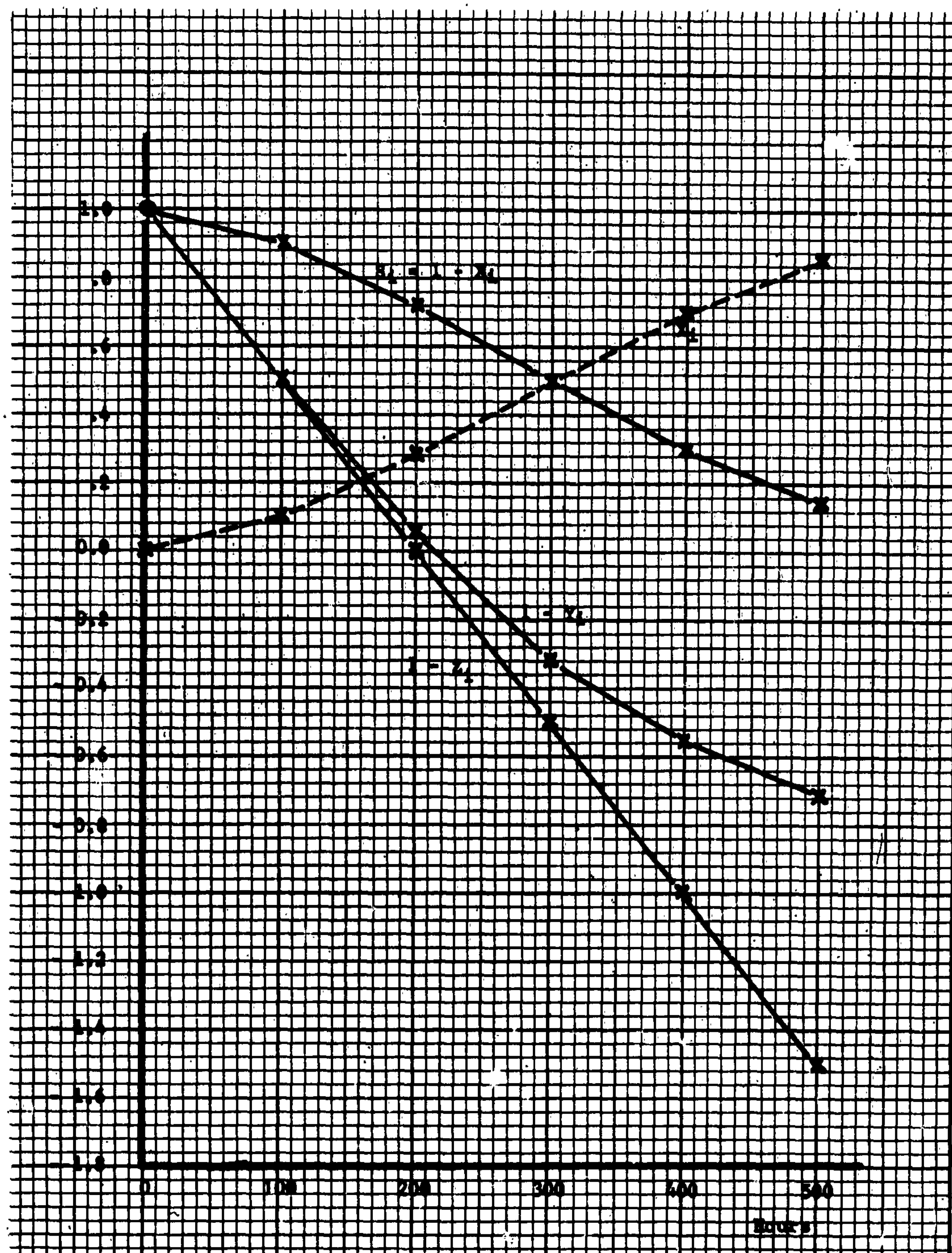
1.0
.8
.6
.4
.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
0
100
200
300
400
500
Hours
$Y_i = 1 - X_i$
X_i

Figure B-1

For each of the failing fractions x_i, y_i, and z_i, the example also shows the cumulative totals X_i, Y_i, and Z_i. X_i, the fraction of items which do not reach the end of the i th interval, is evidently equal to $1-S_i$. We notice, for example, how 49.6% of the items ($= X_3$) do not reach 300 hours, which is the same as saying that the surviving fraction at 300 hours is .504 ($= S_3$). The Survival Probability Curve (S_i) therefore is identical to the Cumulative Overhaul Failures Curve (X_i), see Figure B-1, except that it is plotted from the point 1.0 downwards instead of from the point 0.0 upwards. Following this analogy, Figure B-1 also shows a Cumulative Removals Curve plotted from 1.0 downwards ($1-Y_i$) and similarly the complement to the Cumulative Removals (Repair Everything) Curve ($1-Z_i$).

In conclusion, the following recursive formulas describe the Actuarial Model:

$$x_i = f_i' \, S_{i-1} \quad , \text{ with } S_o = 1.0 \quad \dots\dots\dots\dots \; (1)$$

$$X_i = X_{i-1} + x_i \quad , \text{ with } X_o = 0.0 \quad \dots\dots\dots\dots \; (2)$$

$$S_i = S_{i-1} - x_i = 1-X_i \quad \dots\dots\dots\dots \; (3)$$

$$y_i = f_i \, S_{i-1} \quad \dots\dots\dots\dots \; (4)$$

$$Y_i = Y_{i-1} + y_i \quad , \text{ with } Y_o = 0.0 \quad \dots\dots\dots\dots \; (5)$$

$$z_i = f_i \quad \dots\dots\dots\dots \; (6)$$

$$Z_i = Z_{i-1} + z_i \quad , \text{ with } Z_o = 0.0 \quad \dots\dots\dots\dots \; (7)$$

$$r_i = f_i' / f_i \quad \dots\dots\dots\dots \; (8)$$

THE FORECASTING CYCLE: SUMMARY

Display and Smoothing of Crude Actuarial Data:

$$\boxed{\begin{array}{c} f_i \\ f_i' \end{array}} \xrightarrow{S_0=1,\; X_0=0,\; Y_0=0,\; Z_0=0} \boxed{\begin{array}{ll} y_i = f_i\, S_{i-1} & Y_i = Y_{i-1} + y_i \\ x_i = f_i'\, S_{i-1} & X_i = X_{i-1} + x_i \\ S_i = S_{i-1} - x_i & Z_i = Z_{i-1} + f_i \end{array}} \xrightarrow{\text{plot}} \boxed{\begin{array}{c} S_i \\ 1 - Z_i \\ 1 - Y_i \end{array}} \xrightarrow{\text{smooth}} \boxed{\begin{array}{c} \hat{S}_i \\ 1 - \hat{Z}_i \end{array}}$$

Reduction of Smoothed Curves:

$$\boxed{\begin{array}{c} \hat{X}_i = 1 - \hat{S}_i \\ 1 - \hat{Z}_i \end{array}} \longrightarrow \boxed{\begin{array}{l} \hat{x}_i = \hat{X}_i - \hat{X}_{i-1} \\ \hat{f}_i' = \hat{x}_i \,/\, \hat{S}_{i-1} \\ \hat{f}_i = \hat{Z}_i - \hat{Z}_{i-1} \end{array}} \longrightarrow \boxed{\begin{array}{l} \hat{r}_i = \hat{f}_i' \,/\, \hat{f}_i \\ \widehat{MTBO} = \ldots\ldots (9) \\ \widehat{MTBR} = \ldots\ldots (10) \end{array}} \xrightarrow{\text{plot}} \boxed{\begin{array}{c} \hat{r}_i \\ 1 - \hat{Z}_i \end{array}}$$

Projections for Next Year and Long Term:

$$\boxed{\begin{array}{c} \hat{f}_i \\ 1 - \hat{Z}_i \end{array}} \xrightarrow{\text{project}} \boxed{\begin{array}{c} \hat{\hat{f}}_i \\ 1 - \hat{\hat{Z}}_i \end{array}} \longrightarrow \boxed{\begin{array}{l} \hat{\hat{f}}_i = \hat{\hat{Z}}_i - \hat{\hat{Z}}_{i-1} \\ \hat{\hat{f}}_i' = \hat{\hat{f}}_i\, \hat{r}_i \end{array}} \longrightarrow \boxed{\begin{array}{l} \hat{\hat{x}}_i = \hat{\hat{f}}_i'\, \hat{\hat{S}}_{i-1} \\ \hat{\hat{S}}_i = \hat{\hat{S}}_{i-1} - \hat{\hat{x}}_i \\ \widehat{\widehat{MTBO}} = \ldots\ldots (9) \\ \widehat{\widehat{MTBR}} = \ldots\ldots (10) \end{array}}$$

Making the Forecast:

$$\boxed{\begin{array}{l} \text{Given: } n_i\text{'s}, \; i = 1, 2, \ldots, n \\ \text{compute } {}^0N_i = \dfrac{n_i}{\hat{\hat{S}}_{i-1}}, \; i = 1, 2, \ldots, n \\ \text{set } {}^0O = {}^0R = 0 \end{array}} \longrightarrow \boxed{\begin{array}{ll} \text{after } k \text{ cycles, } k = 1, 2, \ldots: & \\ {}^kN_i = {}^{k-1}N_{i-1}, \; i = 2, 3, \ldots, n & \\ {}^kN_1 = \sum_{i=1}^{n} {}^{k-1}N_i\, \hat{\hat{x}}_i & \\ {}^kO = {}^{k-1}O + {}^kN_1 & = \text{number of overhauls} \\ {}^kR = {}^{k-1}R + \sum_{i=1}^{n} {}^{k-1}N_i\, (\hat{\hat{y}}_i - \hat{\hat{x}}_i) & = \text{number of repairs} \end{array}}$$

and furthermore (n = number of intervals of T hours each):

$$\text{MTBO} = T \times (1/2 - 1/2\, S_n + \sum_{i=1}^{n} S_i) \qquad \text{............ (9)}$$

$$\text{MTBR} = \text{MTBO} \Big/ \sum_{i=0}^{n} f_{i+1}\, S_i \qquad , \text{ with } f_{n+1} = 1.0 \qquad \text{............ (10)}$$

with the following reversals:

$$x_i = X_i - X_{i-1} \qquad \text{............ (2')}$$

$$f_i' = x_i / S_{i-1} \qquad \text{............ (4')}$$

$$f_i = Z_i - Z_{i-1} \qquad \text{............ (9')}$$

$$f_i' = f_i\, r_i \qquad \text{............ (8')}$$

THE FORECASTING CYCLE

This section highlights the methods applicable to the Forecasting Cycle as presented in Figure 6.20, page 75. The computation of exposures and failures by interval from the item histories and the resulting actuarial failure rates has been covered extensively in Section 6.1 and the exposition which follows emphazises the manipulation of these rates to finally arrive at a forecast. Figure 6.20 is adhered to in a general sense, but should not be taken literally in as much as its function was to communicate the idea of how forecasts would be made and not the details. The different operations constituting the forecasting cycle are summarized on the opposite page under the appropriate headings.

Display and Smoothing of Actuarial Data: Actuarial failure rates do not lend themselves to display in crude form unless the number of observed failures is very large, which is not normally the case. Rather than trying to plot the highly unstable failure rates by interval and drawing some smooth line through these points, it is very much easier and more accurate to plot a cumulative quantity such as the surviving fraction, S_i. Where repair is an issue the Survival Probability Curve has to be supplemented with at least one cumulative curve portraying the effect of all removals rather than just overhauls. The hypothetical Cumulative Removals (Repair Everything) Curve ($1-Z_i$) is most appropriate since it will be used later on for making long-term projections, but $1-Y_i$ may also be displayed. The smoothed version of the S_i and $1-Z_i$ curves is indicated as $\hat{S}_i$ and $1-\hat{Z}_i$.

Reduction of Smoothed Curves: the smoothed curves $\hat{S}_i = 1-\hat{X}_i$ and $1-\hat{Z}_i$ can now be used to recompute the smoothed failure rates $\hat{f}_i$ and $\hat{f}'_i$ and to derive other quantities of interest. For projecting into the future it is advantageous to separately consider changes in repair policy (the repair versus overhaul decision) and improvements in failure rates. A Survival Probability Curve, for instance, is not a very good basis for projections because it is the joint result of item reliability and repair decisions. Instead of Survival Probabilities, therefore, projections are made of the Cumulative Removals Curve $1-Z_i$ which is pure reliability, complemented with the Overhaul Ratio Curve (r_i) which reflects the repair policy only. The smoothed $1-\hat{Z}_i$ is already available at this stage, but the smoothed $\hat{r}_i$ has to be computed. MTBO and MTBR are determined for comparison with projected results.

Projections for Next Year and Long Term: the smoothed Overhaul Ratio Curve $\hat{r}_i$ and Cumulative Removals Curve $1-\hat{Z}_i$ reflecting last year's actual experience serve as the input to the projections for the next fiscal year and for the long term. These projections themselves take the form of r_i and $1-Z_i$ curves*, now designated $\hat{\hat{r}}_i$ and $1-\hat{\hat{Z}}_i$ to distinguish them from the smoothed curves $\hat{r}_i$ and $1-\hat{Z}_i$. Two sets of $\hat{\hat{r}}_i$ and $1-\hat{\hat{Z}}_i$ curves are needed, one for next year and one for the long term. The projected Overhaul Ratio and Cumulative Removals Curves are again reduced to failure rates, survival probabilities, MTBO, and MTBR.

Making the Forecast: the forecast of the long-term repair and overhaul rates is simply obtained by dividing the total number of flying hours forecast by the MTBR and MTBO respectively. But in forecasting next year's rates it may be necessary to consider the current ages of installed items, the thought being that if installed items are all relatively newly installed with few hours logged, fewer removals will take place, but if the installed population has a high proportion of items near the TBO, more removals can be expected. The forecast is then made by starting with the current age distribution of the installed population and "operating" these items on paper as it were until the required number of hours has been flown, keeping track of overhauls and removals. Figure B-2 outlines the chain of events set off by having n_i items in interval i to start with. If these n_i items

*Here we deviate from Figure 6.20 where it is shown that a long-term projection of the Survival Probability Curve, S_i, is made.

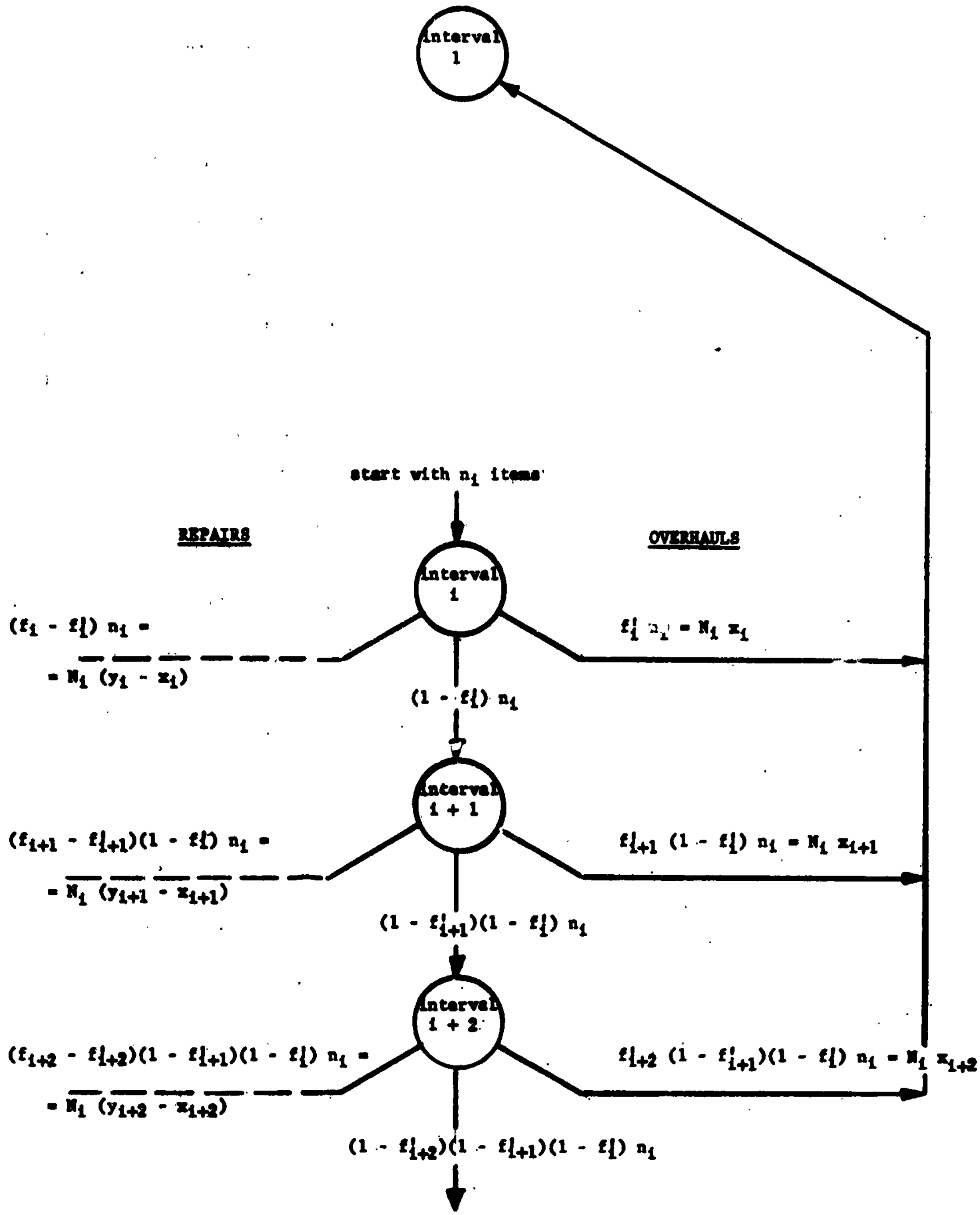
Interval 1
start with n_i items
REPAIRS
OVERHAULS
Interval i
$(f_i - f_i') n_i =$
$= N_i (y_i - x_i)$
$f_i' n_i = N_i x_i$
$(1 - f_i') n_i$
Interval i + 1
$(f_{i+1} - f_{i+1}')(1 - f_i') n_i =$
$= N_i (y_{i+1} - x_{i+1})$
$f_{i+1}' (1 - f_i') n_i = N_i x_{i+1}$
$(1 - f_{i+1}')(1 - f_i') n_i$
Interval i + 2
$(f_{i+2} - f_{i+2}')(1 - f_{i+1}')(1 - f_i') n_i =$
$= N_i (y_{i+2} - x_{i+2})$
$f_{i+2}' (1 - f_{i+1}')(1 - f_i') n_i = N_i x_{i+2}$
$(1 - f_{i+2}')(1 - f_{i+1}')(1 - f_i') n_i$

Figure B-2

are exposed to one interval's worth of flying (T hours), we can expect f_i' n_i to fail resulting in overhaul, the rest $(1-f_i')$ n_i to enter the next interval i+1. The total number of removals, including premature failures that are repaired, would be f_i n_i. In order to effectively deal with overhauls and repairs we have to make the assumption that a repair removal does not alter the age composition of the installed population, but that the replacement item will be of the same age as the removed items. In so far as the transferring of items from one age interval to another is concerned, we can then ignore repair removals entirely, which is what the dotted lines in Figure B-2 indicate, by leading nowhere. Overhaul removals, however, are assumed to be replaced by freshly overhauled items, which is why the f_i' n_i items which failed are shown as ending up in the first interval. Of the $(1-f_i')$ n_i items which entered the $i+1^{st}$ interval, a fraction, f_{i+1}' will fail for overhaul if exposed to the second cycle of exposure, (another T hours) giving f_{i+1}' $(1-f_i')$ n_i overhaul removals. Similarly we expect $(f_{i+1} - f_{i+1}')$ $(1-f_i')$ n_i repair removals. After "flying" each item through 2 cycles of T hours each, $(1-f_{i+1}')$ $(1-f_i')$ n_i will have entered into the i+2nd interval, etc. One continues doing this until the forecasted number of hours per aircraft has been completed. For example, if the forecast has each plane fly an average of 300 hours, and intervals are 50 hours each, then 6 cycles are executed. The computations involved are greatly simplified by recognizing that the number of overhaul removals in the first cycle as the result of having n_i items in interval i to start with, equals:

$$f_i' \, n_i = \left(\frac{n_i}{S_{i-1}}\right) x \, (f_i' \, S_{i-1}) = N_i \, x_i$$

where: $N_i = \frac{n_i}{S_{i-1}}$

and the number of overhaul removals in the i+1st interval (2nd cycle) resulting from the survivors among the n_i equals:

$$f_{i+1}' \, (1-f_i') \, n_i = \frac{n_i}{S_{i-1}} \, S_{i-1} \, (1-f_i') \, f_{i+1}'$$

which reduces to: $N_i \, x_{i+1}$

similarly in the i+2nd interval (3rd cycle)

$$f_{i+2}' \, (1-f_{i+1}') \, (1-f_i') \, n_i = N_i \, x_{i+2}$$

The same simplifications can be made in the case of the repair removals. All that is required, then, is to divide the starting age distribution (n_i's) by the appropriate survival probabilities (S_{i-1}) to arrive at the values of N_i for each interval i. Failures are subsequently generated by multiplying by the failing fractions (x_i for overhaul, $y_i - x_i$ for repair). Overhaul removals in each cycle make up the N_1 for the next cycle and furthermore N_1's keep moving to the next higher interval with each cycle until they reach the last interval (i=n=TBO/T). The number of cycles that have to be completed is equal to the flying hours forecast per aircraft divided by the length of an interval, T.

THE WORLD-WIDE INVENTORY MODEL

DEFINITIONS

NICP repair cycle: sum of unserviceables in transit to NICP, unserviceables on hand and in overhaul/repair at NICP

T : NICP repair cycle time; average time to restore an unserviceable engine to serviceable condition at the national level, counting from the day an unserviceable engine leaves the area until completion of overhaul/repair

${}_s t_i$: average time delay in replenishing area i from the national level, counting from the day the unserviceable engine is removed from the aircraft until the day the replacement engine is received in the area, assuming the NICP is not out of stock

${}_r t_i$: average in-area repair cycle time counting from the day the unserviceable engine is removed from the aircraft until the day it has been returned to serviceable stock

τ : average delay in filling a field replenishment demand as the result of national unavailability

λ_i : total removal rate for area i

λ_i' : evacuation rate for area i; those items which are returned to the NICP rather than repaired locally

μ : total rate of replenishment demands on NICP; equals $\Sigma\lambda_i'$

M : NICP stock level covering NICP repair cycle and serviceables on hand

r_i : stock level assigned to area i covering in-area repair cycle, serviceables in transit from NICP and on-hand engines

N : net serviceable inventory at NICP; equals on hand minus backorders

p(N) : probability of N

n_i : net serviceable inventory in area i; equals on hand minus backorders

$p(n_i)$: probability of n_i

$p\ (x;\ \lambda t)$: probability of x actions in period t when mean action rate is λ; equals $[e^{-\lambda t}\ (\lambda t)^x\ ]\ 1/x!$ for Poisson distribution

b_i : average number of backorders in area i

W : average customer waiting time

NATIONAL AVAILABILITY

The function of the serviceable engines on hand at the national level is to protect the NICP against stock-outs resulting from variations in the rate of replenishment demands from the areas, μ, combined with a time lag, T, in getting removed engines back into serviceable condition.

The number of items in the NICP repair cycle is on the average equal to μT but fluctuates around this average according to the Poisson distribution. If at times the number of these unserviceables exceeds the NICP stock level, M, then the NICP is out of stock, meaning that replenishment shipments to the field level are delayed.

The probability distribution of net stock at the NICP level can be expressed as:

$$p(N) = p(M-N;\ \mu T)$$

resulting in an average delay

$$\tau = (1/\mu) \sum_{N=-1}^{-\infty} (-N)\ p(N)$$

AVERAGE CUSTOMER WAITING TIME

Similarly, the inventory assigned to the areas, r_i, serves the purpose of protecting the areas against stock-outs resulting from variations in the rate of demands for replacement engines, λ_i, combined with time lags for local repair, ${}_rt_i$, and for replenishment shipment from the NICP, ${}_st_i + \tau$. It can be shown that the average number of items tied up in the area's pipelines equals $(\lambda_i - \lambda_i')\,{}_rt_i + \lambda_i'\,({}_st_i + \tau)$, but fluctuates around this average according to the Poisson distribution. The inclusion of a factor $\lambda_i'\tau$ in the above expression reflects that an evacuation of an unserviceable engine from the area may not immediately be followed by a replenishment shipment from the NICP because, as has been discussed in the previous section, the NICP does not always have serviceables on hand.

A stock-out in the area inevitably results if at any time the number of items tied up in the area's pipelines exceeds the area's stock level r_i. The probability distribution of an area's net stock can be expressed as:

$$p(n_i) = p(r_i - n_i;\ (\lambda_i - \lambda_i')\ {}_r t_i + \lambda_i'\ ({}_s t_i + \tau))$$

The average number of backorders in the area is thus:

$$b_i = \sum_{n_i=-1}^{-\infty} (-n_i)\ p(n_i)$$

The average customer wait, weighing all areas:

$$W = (1/\sum_i \lambda_i) \sum_i b_i$$

"OPTIMAL" DISTRIBUTION OF SPARES

One of the questions one might ask is how should a given total number of spares, I, be allocated over the national level and over the different areas at the field level, for minimal average customer waiting time

$$\text{Min } W\ (M,\ r_i,\ i=1,2,\ .\ .\ .\ )\ \text{subject to } M + \sum_i r_i \leq I$$

Characteristics of the "optimum" are:

(1) Subtracting one engine from any one area's stock level and adding it to some other area will not improve the average customer wait for the system as a whole

(2) Subtracting one engine from the NICP stock level and adding it to no matter which area has the same effect

One can converge onto this optimum with the following iterative procedure:

(1) $M = I$; $r_i = 0$ for all i. Compute W

(2) For $k = 1,2, \ldots$ compute W_k with M-1 and $r_k = r_k + 1$, leaving $r_i = r_i$, all $i \neq k$

(3) $\min_k W_k < W$? If yes: set $W = W_k$, $r_k = r_k + 1$ and return to (2)

if not: W is optimal

DESCRIPTION OF THE COMPUTER PROGRAM

The object of the program is to compute optimal Area Inventory Levels, i.e., those levels which will result in the shortest possible average customer wait for the system overall. The main program (see FORTRAN listing on page 8 and flow chart on page 10 of this Appendix) is entered with the following data in memory:

MAD = number of areas

TUAT = T, NICP repair cycle, days

INV = I, total spares

ALAP = the accuracy with which computations of probabilities are to be carried out. We have used ALAP = 10^{-5} with good results

APP(I) = a table of the cumulative normal distribution, where

I goes from 1 to 400. These constants are printed out, 10 to a line, on page 11 of this Appendix

and for each area I:

ALAMB(I) = λ_i , removals/year

AMBDA(I) = λ_i' , evacuations/year

TSHIP(I) = ${}_s t_i$, replenishment cycle, days

TREP(I) = ${}_r t_i$, local repair cycle, days

Other symbolic names used include:

UM = μ , total evacuations/year

B = μT , average NICP repair cycle contents

ADELD(I) = ${}_r t_i \, (\lambda_i - \lambda_i') + {}_s t_i \, (\lambda_i')$, average area delay time

MM = NICP stock level

NR(I) = area inventory level

Upon EXIT of the program, the current values of MM and NR(I) are the optimal ones, OPERFO is equal to the system-wide average backorders under this optimal distribution plan. The overall average wait can then be computed by dividing OPERFO by the total removal rate.

Page 9 contains a FORTRAN listing of the subprograms called upon by the main program, namely:

SUBROUTINE PTAB, which computes the terms of the Poisson distribution with mean A (A $\leq$ 100) from:

$$PA(NX) = [e^{-A} \; A^{NX}]/NX!$$

SUBROUTINE NAPX, which approximates the Poisson distribution using the Normal distribution with mean A ($A > 100$) and standard deviation equal to the square root of A.

FUNCTION NEXT, which is used for rounding.

MAIN PROGRAM FORTRAN LISTING

```
      UM: 0.0
      DO 27 I :1,MAD
   27 UM : UM + AMBDA ( I )
      MM : INV
      B : UM * TUAT / 365.
      DO 26 I :1,MAD
      ADELD(I) :(TREP(I) * (ALAMB(I) - AMBDA(I))+ TSIMP(I)*AMBDA(I))/
     1 365.0
      NR(I) : ADELD(I)
   26 MM : MM - NR(I)
      IF ( B- 100.0) 656,656,657
C
C     COMPUTE  P  TABLE
  656 CALL PTAB (B,ALAP,P,MXBTAB)
      GO TO 702
  657 CALL NAPX (B, ALAP, APP, P, MXBTAB)
  702 ASSIGN  34  TO NOS
C
C     AVE  BACKORDERS  NICP
   36 NSTEVE : MXBTAB - MM
      BAVG  :  0.0
      DO  2  MD  :  2  , NSTEVE
      N  :  MM +  MD
      XN  :  MD - 1
    2 BAVG : BAVG + XN * P(N)
      DO  777  I    :  1 , MAD
  777 CALL PTAB (ADELD(I) +BAVG/UM*AMBDA(I),ALAP,PA(1,I),NSLEEP(I))
  619 DO 25  IMP : 1  ,MAD
      NDJH  :  NSLEEP (IMP) - NR (IMP) - 1
      PERFO  (IMP )  :  0.0
      DO  25  MD : 1 , NDJH
      XN  :  MD
      N  :  NR (IMP )  +  MD  +  1
   25 PERFO(IMP) : PERFO(IMP) + XN* PA(N,IMP)
      GO TO NOS, (37,34,617,658)
   34 OPERFO : 0.0
      DO  655  I  :  1 , MAD
  655 OPERFO : OPERFO + ESEN(I)*PERFO(I)
C
C       DECREASE  M
  641  MM : MM-1
      ASSIGN   37  TO NOS
      GO TO 36
   37 PDBPR : 0.0
      DO 38 I : 1,MAD
   38 PDBPR : PDBPR + ESEN(I)*PERFO(I)
C
C      INCREASE  R
   49 ASSIGN  617  TO NOS
      DO 615 INP : 1,MAD
      XPERFO(IMP) : PDBPR -ESEN(IMP)* PERFO(IMP)
  615 NR(IMP) :NR(IMP) + 1
      GO TO 619
  617 DO 29 IMP : 1,MAD
   28 PP(IMP) : XPERFO(IMP)+ ESEN(IMP) * PERFO(IMP)
   29 NR(IMP) : NR(IMP) - 1
C
C       FIND  AREA FOR  BEST  PERF
      PKPR : PP(1)
      NO : 1
      DO 650  I : 2,MAD
      IF (PKPR - PP(I))   650,650,651
  651 PKPR : PP(I)
      NO : I
  650 CONTINUE
      IF (PKPR - OPERFO)  39, 40, 40
   39 NR(NO) : NR(NO) + 1
      OPERFO  :  PKPR
      GO TO 641
   40 MM :MM + 1
```

FORTRAN LISTING OF SUBROUTINES

```
      SUBROUTINE PTAB (A,ALAP,   PA,NSLEEP)
      DIMENSION   PA (500)
      XMOD : MIN1F (1.0, EXPF(85.0 -A))
      PINC   : EXPF ( - MIN1F (A , 85.0 ))
      PA(1) : PINC * XMOD
      DO 624 NX : 2,500
      X : NX - 1
      PINC : PINC * (A/X)
      PA(NX) : PINC * XMOD
      IF(X-A) 624,624,629
  629 IF(PA(NX)-ALAP) 628,624,624
  624  CONTINUE
  628 NSLEEP : NX-1
  622 RETURN
      END
C
C
      SUBROUTINE NAPX (B,ALAP,APP,PA,NSLEEP)
      DIMENSION PA(1000), APP(400)
      MU : NEXT (B + 1.)
      OM : 100. / SQRTF (B)
      SOM : .5 * OM + 1.
      IX : XINTF(SOM)
      CUMPRO : APP(IX) + MODF(SOM,1.)*(APP(IX + 1)-APP(IX))
      PA(MU) : 2.*CUMPRO - 1.0
      NEG : 1
    3 PREV : CUMPRO
      SOM : SOM + OM
      IX : XINTF(SOM)
      IF (IX - 395)  14,14,15
   14 CUMPRO : APP(IX) + MODF(SOM,1.)*(APP(IX + 1) - APP(IX))
      TERM : CUMPRO - PREV
      IF (TERM - ALAP )  15,15,  5
    5 MUPLUS : MU + NEG
      PA(MUPLUS) : TERM
      MUMINU : MU - NEG
      PA(MUMINU) : TERM
    8  NEG : NEG + 1
      GO TO 3
   15 NSLEEP : MU + NEG - 1
      LPTWFP : MUMINU -1
      DO 4 I : 1,LPTWFP
    4 PA(I) : 0.0
      RETURN
      END
C
C
      FUNCTION  NEXT (TOBER)
      NEXT : XINTF (TOBER)
      IF(MODF(TOBER,1.) - .5) 1,2,2
    2 NEXT : NEXT + 1
    1 RETURN
      END
```

MAIN PROGRAM FLOWCHART
(input and output excluded)

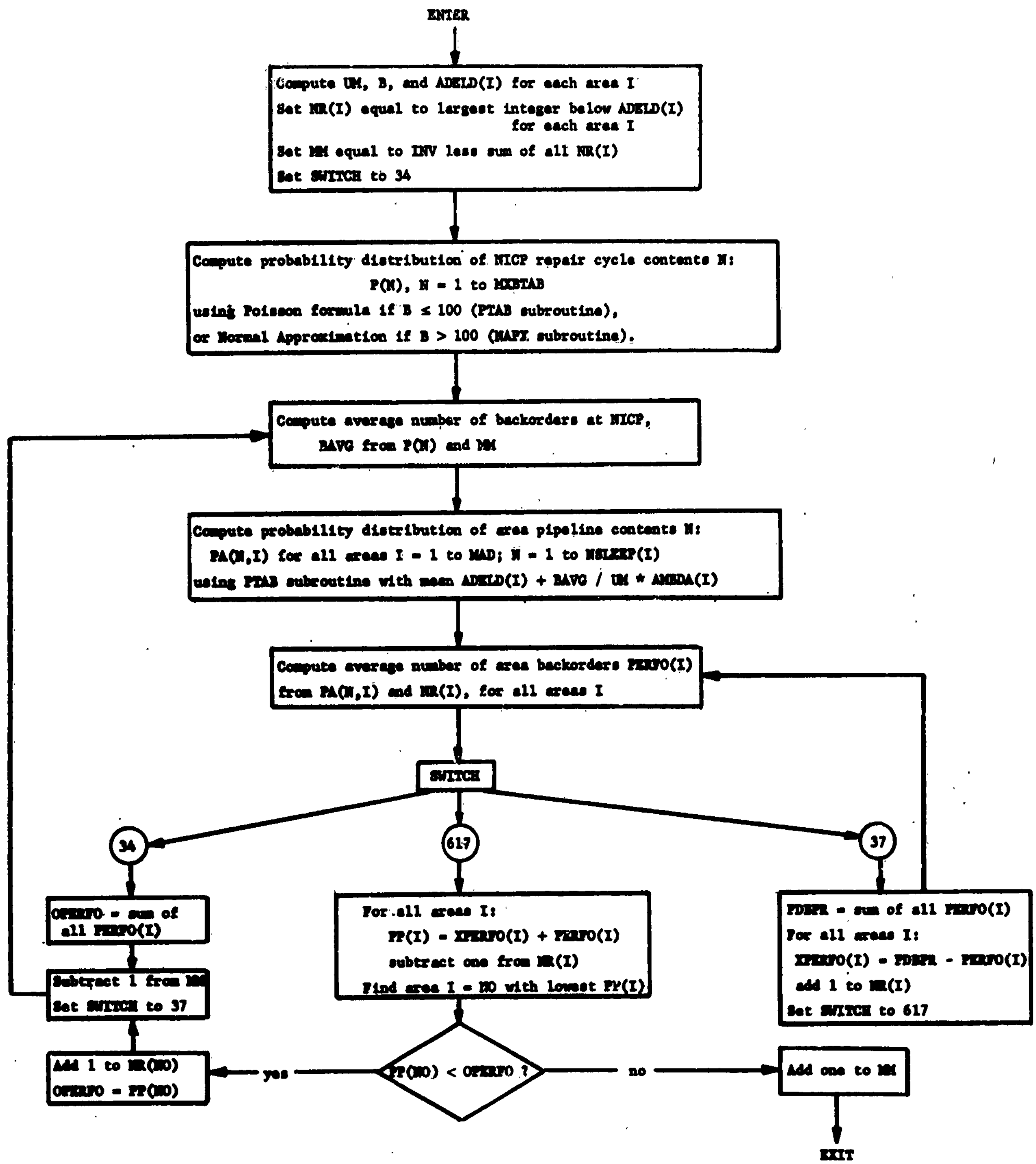

TABLE OF CONSTANTS FOR USE BY
NAPX SUBROUTINE

.500000	.503989	.507978	.511966	.515953	.519939	.523922	.527903	.531881	.535856
.539828	.543795	.547758	.551717	.555670	.559618	.563559	.567495	.571424	.575345
.579260	.583166	.587064	.590954	.594835	.598706	.602568	.606420	.610261	.614092
.617911	.621720	.625516	.629300	.633072	.636831	.640576	.644309	.648027	.651732
.655422	.659097	.662757	.666402	.670031	.673645	.677242	.680822	.684386	.687933
.691462	.694974	.698468	.701944	.705401	.708840	.712260	.715661	.719043	.722405
.725747	.729069	.732371	.735653	.738914	.742154	.745373	.748571	.751748	.754903
.758036	.761148	.764238	.767305	.770350	.773373	.776373	.779350	.782305	.785236
.788145	.791030	.793892	.796731	.799546	.802337	.805105	.807850	.810570	.813267
.815940	.818589	.821214	.823814	.826391	.828944	.831472	.833977	.836457	.838913
.841345	.843752	.846236	.848495	.850830	.853141	.855428	.857690	.859929	.862143
.864334	.866500	.868643	.870762	.872857	.874928	.876976	.879000	.881000	.882977
.884930	.886861	.888768	.890651	.892512	.894350	.896165	.897958	.899727	.901475
.903200	.904902	.906582	.908241	.909877	.911492	.913085	.914657	.916207	.917736
.919243	.920730	.922196	.923641	.925066	.926471	.927855	.929219	.930563	.931888
.933193	.934478	.935745	[illegible]992	.938220	.939429	.940620	.941792	.942947	.944083
.945201	.946301	.947384	.948449	.949497	.950529	.951543	.952540	.953521	.954486
.955435	.956367	.957284	.958185	.959070	.959941	.960796	.961636	.962462	.963273
.964070	.964852	.965620	.966375	.967116	.967843	.968557	.969258	.969946	.970621
.971283	.971933	.972571	.973197	.973810	.974412	.975002	.975581	.976148	.976705
.977250	.977784	.978308	.978822	.979325	.979818	.980301	.980774	.981237	.981691
.982136	.982571	.982997	.983414	.983823	.984222	.984614	.984997	.985371	.985738
.986097	.986447	.986791	.987126	.987455	.987776	.988089	.988396	.988696	.988989
.989276	.989556	.989830	.990097	.990358	.990613	.990863	.991106	.991344	.991576
.991802	.992024	.992240	.992451	.992656	.992857	.993053	.993244	.993431	.993613
.993790	.993963	.994132	.994297	.994457	.994614	.994766	.994915	.995060	.995201
.995339	.995473	.995604	.995731	.995855	.995975	.996093	.996207	.996319	.996427
.996533	.996636	.996736	.996833	.996928	.997020	.997110	.997197	.997282	.997365
.997445	.997523	.997599	.997673	.997744	.997814	.997882	.997948	.998012	.998074
.998134	.998193	.998250	.998305	.998359	.998411	.998462	.998511	.998559	.998605
.998650	.998694	.998736	.998777	.998817	.998856	.998893	.998930	.998965	.998999
.999032	.999065	.999096	.999126	.999155	.999184	.999211	.999238	.999264	.999289
.999313	.999336	.999359	.999381	.999402	.999423	.999443	.999462	.999481	.999499
.999517	.999534	.999550	.999566	.999581	.999596	.999610	.999624	.999638	.999651
.999663	.999675	.999687	.999698	.999709	.999720	.999730	.999740	.999749	.999758
.999767	.999776	.999784	.999792	.999800	.999807	.999815	.999822	.999828	.999835
.999841	.999847	.999853	.999858	.999864	.999869	.999874	.999879	.999883	.999888
.999892	.999896	.999900	.999904	.999908	.999912	.999915	.999918	.999922	.999925
.999928	.999931	.999933	.999936	.999938	.999941	.999943	.999946	.999948	.999950
.999952	.999954	.999956	.999958	.999959	.999961	.999963	.999964	.999966	.999967

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3. REPORT TITLE
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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report

5. AUTHOR(S) (Last name, first name, initial)
Rosenman, Bernard B., and Hoekstra, Djoerd

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
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	U.S. Army Supply and Maintenance Command Bailey's Crossroads, Virginia

13. ABSTRACT

The report describes a system for the supply management of high-value Army Aircraft components. The system is based upon the calculation, first, of a long-term Desired Inventory Level, which is the number of spares needed to provide some desired level of customer service, expressed in terms of the average length of time a field customer has to wait for a serviceable replacement spare, after product improvements have been realized and pipeline times have reached standard levels. The current spares assets are then used, along with current failure rates, and pipline times to calculate the current average customer wait under an optimal plan of distributing spares among geographical areas. Procurement and overhaul budgets and other management control actions are to be made considering current needs as characterized by the average customer wait and future requirements reflected in the Desired Inventory Level. It is proposed to use the Actuarial Method now in use in the USAF for forecasting time-change and premature removals of components and to use exponential smoothing methods for tracking program factors, pipeline times, removal rates, etc. (Authors).

DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Requirements computation, World-Wide Inventory Model, Repair Cycle, Actuarial Forecasting Procedure, Poisson Probability Distribution, Optimal geographical distribution of spare components.						

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